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Simulation of Ground-Water Flow in the Potomac-Raritan-Magothy Aquifer System, Pennsauken Township and Vicinity, New Jersey

U.S. Geological Survey Scientific-Investigations Report 2004-5025

U.S. Department of the Interior
U.S. Geological Survey

Simulation of Ground-Water Flow in the Potomac-Raritan-Magothy Aquifer System, Pennsauken Township and Vicinity, New Jersey

By Daryll A. Pope and Martha K. Watt

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U.S. Department of the Interior
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Conversion Factors, Datums and Definition

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.09290	square meter (m^3)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	Liter (L)
cubic foot (ft^3)	7.4085	gallon (gal)
	Flow	
million gallons per day (Mgal/d)	0.04381	cubic meters per second (m^3/s)
gallons per minute (gal/min)	0.06308	liter per second (L/s)
	Hydraulic conductivity *	
Foot per day (ft/d)	0.3048	meter per day (m/d)

Datums

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD of 1929); horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Definition

* Hydraulic conductivity: The standard unit for hydraulic conductivity is cubic foot per day per square foot of aquifer cross-sectional area $(ft^3/d)/ft^2$. In this report, the mathematically reduced form, feet per day (ft/d), is used for convenience.

Simulation of Ground-Water Flow in the Potomac-Raritan-Magothy Aquifer System, PennsaukenTownship and Vicinity, New Jersey

by Daryll A. Pope and Martha K. Watt

Abstract

The Potomac-Raritan-Magothy aquifer system is one of the primary sources of potable water in the Coastal Plain of New Jersey, particularly in heavily developed areas along the Delaware River. In Pennsauken Township, Camden County, local drinking-water supplies from this aquifer system have been contaminated by hexavalent chromium at concentrations that exceed the New Jersey maximum contaminant level. In particular, ground water at the Puchack well field has been adversely affected to the point where, since 1984, water is no longer withdrawn from this well field for public supply. The area that contains the Puchack well field was added to the National Priorities List in 1998 as a Superfund site.

The U.S. Geological Survey (USGS) conducted a reconnaissance study from 1996 to 1998 during which hydrogeologic and water-quality data were collected and a ground-water-flow model was developed to describe the conditions in the aquifer system in the Pennsauken Township area. The current investigation by the USGS, in cooperation with the U.S. Environmental Protection Agency (USEPA), is an extension of the previous study. Results of the current study can be applied to a Remedial Investigation and Feasibility Study conducted at the Puchack well field Superfund site.

The USGS study collected additional data on the hydrogeology and water-quality in the area. These data were incorporated into a refined model of the ground-water-flow system in the Potomac-Raritan-Magothy aquifer system. A finite-difference model was developed to simulate ground-water flow and the advective transport of chromium-contaminated ground water in the aquifers of the Potomac-Raritan-Magothy aquifer system in the Pennsauken Township area. An 11-layer model was used to represent the complex hydrogeologic framework. The model was calibrated using steady-state water-level data from March 1998, April 1998, and April 2001. Water-level recovery during the shutdown of Puchack 1 during March to April 1998 was simulated to evaluate model performance in relation to changing stresses. The Delaware River contributes appreciable-flow to the ground-water system from areas where the Middle and Lower aquifers crop out beneath the river. A transient simulation of an aquifer test near the Delaware River was run to help characterize the hydraulic conductivity of the riverbed sediments represented in the model. Vertical flow across confining units between the aquifers is highly variable and is important in the movement of water and associated contaminants through the flow system. The model was imbedded within a regional model of the Potomac-Raritan-Magothy aquifer system in Camden County.

In general, a simulation of baseline conditions, which can provide a representation on which simulations of various alternatives can be based for the feasibility study, incorporated average conditions from 1998 to 2000. Ground-water withdrawals within the model area during this period averaged about 14 Mgal/d. Regional ground-water flow is from recharge areas and from the Delaware River to downgradient pumped wells located just east of the model area in central Camden County. Simulation results show an important connection between the Intermediate sand and the Lower aquifer of the Potomac-Raritan-Magothy aquifer system in the vicinity of the chromium-contaminated area. The Delaware River contributes nearly 10 Mgal/d to the flow system, whereas recharge contributes about 6 Mgal/d. Ground-water withdrawals within the model area account for nearly 14 Mgal/d (mostly from the Lower aquifer of the Potomac-Raritan-Magothy aquifer system).

Introduction

The Potomac-Raritan-Magothy aquifer system is an important source of water supply in northwestern Camden County. Farlekas and others (1976) divided the Potomac-Raritan-Magothy aquifer system in the Camden County area into five layers described as the Upper, Middle, and Lower aquifers separated by two confining units. In the Pennsauken Township area (fig. 1), these aquifers are the principal source of potable water to the city of Camden and the Merchantville-Pennsauken Water Company. Most of the public-supply water withdrawals in this area have been from the Lower aquifer of the Potomac-Raritan-Magothy aquifer system. Because of the importance of the aquifer system as a source of potable water, contamination originating from surficial sources that moves into and through the aquifer system is a matter of concern.

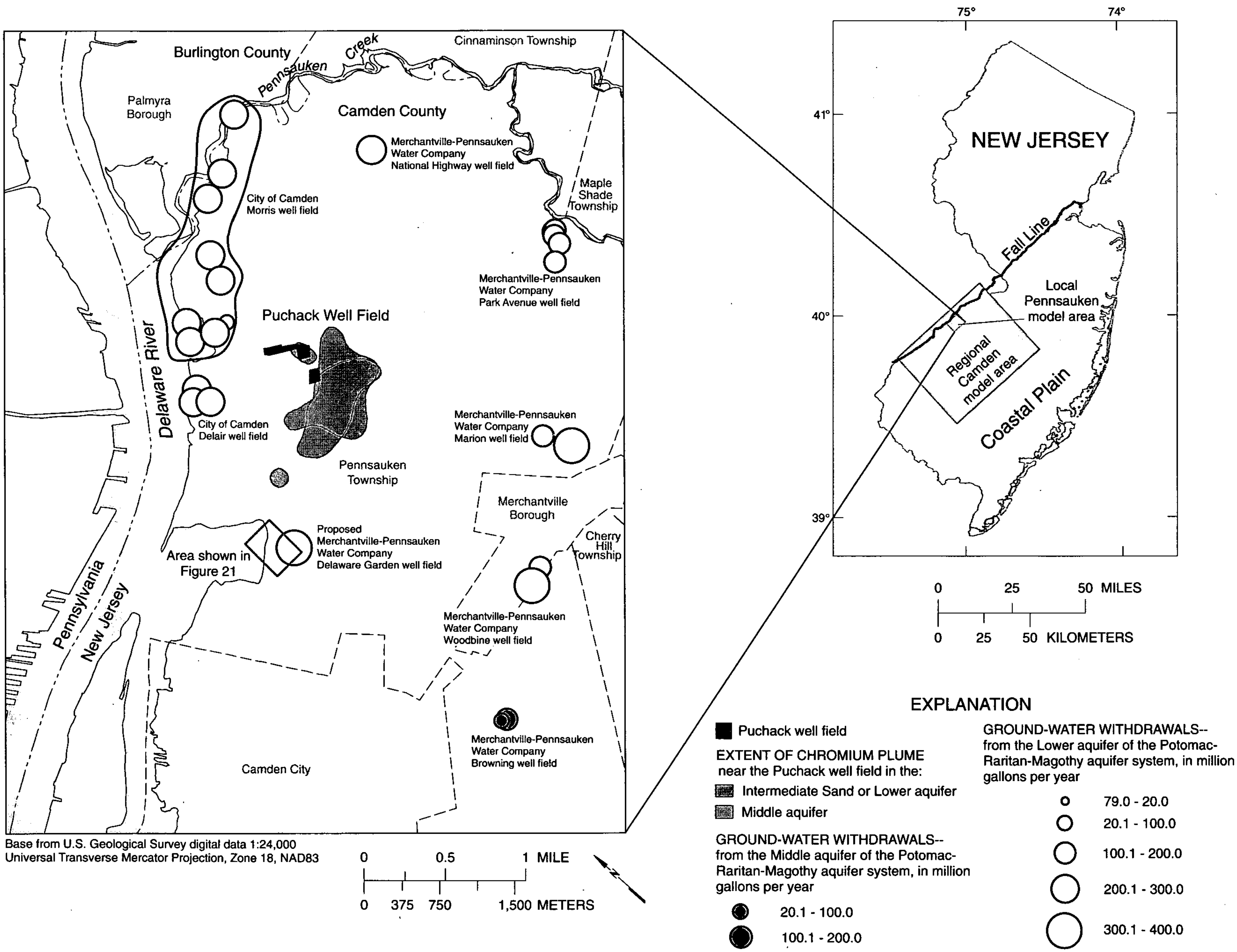

Figure 1. Location of the study area, chromium plumes, and baseline ground-water withdrawals, Pennsauken Township and vicinity, Camden County, New Jersey.

Volatile organic compounds (VOCs) and trace elements, predominantly chromium in the toxic hexavalent form, were identified in water from the city of Camden's Puchack well field in Pennsauken Township during the 1970's (CDM, 1985). Because the quality of the water produced by the Puchack wells was compromised, the city of Camden reduced withdrawals from the well field. This well field previously had provided a substantial part of the water supply for the city. Contaminants continued to be present in the ground water, and use of the Puchack well field ceased by 1984 except for the withdrawals of up to 1 Mgal/d from Puchack 1 instituted by NJDEP as an interim contaminant-plume-control measure. Ground water withdrawn from Puchack 1 was either discharged to Puchack Creek adjacent to the site or was blended with the water supply. The withdrawals from Puchack 1 were intended to maintain a hydraulic gradient towards the well field in an attempt to limit migration of contaminants to downgradient wells. In 1998, withdrawals from Puchack 1 were discontinued.

In 1996, a reconnaissance investigation of the hydrogeology and water quality of the Potomac-Raritan-Magothy aquifer system in Pennsauken Township and vicinity was started by the USGS, in cooperation with the New Jersey Department of Environmental Protection (NJDEP). For that study, wells were installed to investigate the hydrogeologic framework of the aquifer system and to obtain water-level measurements. Synoptic measurements of water levels in the aquifer system made in March 1998, April 1998, and November 1998 were used to create potentiometric-surface maps of the Upper, Middle, and Lower aquifers of the Potomac-Raritan-Magothy aquifer system. Water-quality data were collected in the area to characterize the chromium and VOC contamination. Virtually all of the chromium was present as hexavalent chromium, which is the most toxic form. Hexavalent chromium is present in readily soluble species and, therefore, mobile in ground-water systems. A ground-water-flow model of the Potomac-Raritan-Magothy aquifer system was calibrated to water levels measured in March 1998.

Given the widespread inorganic and organic contamination of ground water underlying Pennsauken Township, the area including and surrounding the Puchack well field was added to the National Priorities List as a Superfund site in 1998 (CDM, 2001). The USGS and U.S. Environmental Protection Agency (USEPA) studied the hydrogeology and ground-water quality of the area in support of a Remedial Investigation and Feasibility Study undertaken by the USEPA. As part of the remedial investigation phase of this study, additional wells were drilled and water-level measurements and water-quality sampling were conducted. Using these additional data, the hydrogeologic framework of the area was revised; the extent of the chromium contamination in the Middle aquifer, the Intermediate sand, and the Lower aquifer was delineated (fig. 1); and potentiometric-surface maps of the aquifers in April 2001 were created.

The USGS in cooperation with the USEPA, revised and updated the ground-water-flow model as part of the feasibility study. The hydrogeologic framework developed in the remedial investigation was incorporated into the model, and the model was recalibrated using additional data collected as part of the remedial investigation. The model was developed to investigate the advective transport of chromium in the ground water and can be used to simulate alternatives for remediation approaches as part of the feasibility study.

Purpose and Scope

This report documents the ground-water-flow model developed to investigate advective transport in the vicinity of the chromium plume near the Puchack well field in Pennsauken Township, Camden County, New Jersey. The report describes the hydrogeology and aquifer properties, estimates of ground-water recharge rates, ground-water withdrawals, the interactions of the ground-water-flow-system with the Delaware River, and interaction with the regional ground-water-flow system. The report presents the approach used to calibrate the flow model, the results of model calibration, and the results of a simulation of baseline conditions that can be compared to various aquifer remedial alternatives. Results of the baseline simulation are shown in illustrations, and a ground-water-flow budget for the Potomac-Raritan-Magothy aquifer system is presented. Simulated and measured water levels and residuals are listed in appendixes.

The model was calibrated using water-levels measured in March 1998 at 78 wells and water-level-recovery data from 22 wells measured in March and April 1998. The model also was calibrated using water-levels measured in April 2001 at 143 wells and vertical differences in water levels measured in 33 nested wells completed in different aquifers. Water-level changes in the pumped well and at seven observation wells were calculated from simulated water-levels and were compared with measured water-level changes from an aquifer test conducted in August 1995.

Previous Investigations

Various regional studies describe the hydrogeologic framework of the Coastal Plain and ground-water flow in the vicinity of Pennsauken Township. Zapecza (1989) describes the hydrogeologic framework of the New Jersey Coastal Plain. Martin (1998) describes ground-water flow in the New Jersey Coastal Plain. Farlekas and others (1976) describe the hydrogeology of Camden County. Navoy and Carleton (1995) describe the hydrogeology of the Camden County area and present a model of the regional ground-water-flow system that provides lateral and vertical boundary flows for the model discussed in this report.

Chromium transport and simulation of ground-water flow at the Puchack well field were first studied in the early 1980's (Camp Dresser and McKee, Inc., 1985). Walker and Jacobsen (2004) present the stratigraphy, water levels, and water quality of the area. Water levels measured during March and April 1998 and the response of the aquifers to the shutdown of the Puchack 1 well are documented in Walker (2001). An investigation of the hydrogeologic framework, water quality, and water levels during 1998 to 2001 is described in Barringer and others (U.S. Geological Survey, written commun., 2003) and in the remedial investigation report for the site (CDM Federal, written commun., 2002).

Well-Numbering System

The well-numbering system used in this report consists of a county code number followed by a sequence number of the well within the county. County codes used in this report are 05 for Burlington County and 07 for Camden County. For example, well number 7-528 represents the 528th well inventoried in Camden County. Construction details for wells referred to in this report are shown in table 1 (at the end of the report).

Hydrogeology and Stratigraphy

The Potomac-Raritan-Magothy aquifer system is composed of the wedge-shaped sequence of sediments of the Potomac Group and the Raritan and Magothy Formations of Cretaceous age. These sediments constitute sand and gravel aquifers with intervening silt and clay confining units that thicken and dip from the western edge of the Coastal Plain at the Fall Line toward the southeast (Zapecza, 1989). The sediments are of fluvial-deltaic-marginal marine origin (Farlekas and others, 1976) and are indicative of a complex depositional and erosional environment. The basal unit of the Potomac Group lies directly on the erosional, pre-Cretaceous bedrock surface.

In previous studies of the area, the Potomac-Raritan-Magothy aquifer system is described as the Upper, Middle, and Lower aquifers and two intervening confining units. The Upper aquifer consists of sands of the Magothy Formation. The Middle and Lower aquifers are composed of sands of the Raritan Formation and the Potomac Group. These sediments crop out as thin bands along both sides of the Delaware River in Pennsylvania and New Jersey and are exposed in the bed of the Delaware River through fluvial dissection and dredging. In downdip areas to the east, successively younger Cretaceous and Tertiary sediments overlie the sediments that compose the Potomac-Raritan-Magothy aquifer system.

In Pennsauken Township and vicinity, permeable layers of sand and gravel of the Tertiary Pensauken Formation and Quaternary deposits cap most of the extent of the outcrops of the Cretaceous sediments that form the Potomac-Raritan-Magothy aquifer system (Farlekas and others, 1976). Sands and gravels of the Pensauken Formation are believed to have been deposited in a fluvial environment in which a series of downcutting channels were incised into the sediments below (Owens and Minard, 1979). The Quaternary deposits grade from gravels and gravelly sand at Trenton, N.J., to clayey silt at Philadelphia, Pa.; the differences in these sediments probably represent a change in depositional environment. The Tertiary and Quaternary surficial units, which are of various thicknesses, are hydraulically connected to the underlying Cretaceous sediments and, therefore, are considered to be part of the Potomac-Raritan-Magothy aquifer system.

Because of the depositional environment of the sediments that compose the aquifer system, discontinuities in individual units are common. Throughout the thickness of the Cretaceous sediments, channels have been cut and filled. Thus, major confining units can contain sand lenses that are local water-bearing zones. Aquifers also can contain clay lenses that serve as local confining units. Major confining units also pinch out in some areas. As a result, the hydraulic connections between the sedimentary units can be complex.

Barringer and others (U.S. Geological Survey, written commun, 2003) describe the hydrogeology and stratigraphy of the Potomac-Raritan-Magothy aquifer system in the study area in detail. The framework described by Walker and Jacobsen (2004) and their naming convention for aquifers and confining units are used in this report. The hydrogeologic units that make up the framework as described in Barringer and others (U.S. Geological Survey, written commun, 2003) are shown in table 2 and are compared to the previous breakdown of hydrogeologic units described in Zapecza (1989), Navoy and Carleton (1995), and Farlekas and others (1976).

Simulation of Ground-Water Flow

A ground-water-flow model was developed to simulate the advective movement of chromium contaminated ground water towards potential receptor wells. Because of the highly permeable aquifers and large vertical component of flow, advection is the main component of chromium transport. The flow model was calibrated to available steady-state and transient data. The model then was used to simulate the ground-water-flow system using baseline conditions to serve as the basis for comparing simulations of various aquifer remediation alternatives.

Model Development

A three-dimensional, finite difference ground-water-flow model was used to simulate ground-water flow in the Potomac-Raritan-Magothy aquifer system in Pennsauken Township and surrounding areas. The ground-water-flow system was simulated using the USGS modular model (MODFLOW-2000) by Harbaugh and others (2000). Data input was processed using the MFI2K preprocessor (Harbaugh, 2002). Other packages were used with MODFLOW2000. The Link-AMG (LMG) package (Mehl and Hill, 2001) was used as a solver, and the Flow and Head Boundary (FHB1) package (Leake and Lilly, 1997) was used to input the boundary flows from the regional Camden model (Navoy and Carleton, 1995).

Table 1. Well-construction data for wells used in the development and calibration of the Pennsauken ground-water-flow model, Pennsauken Township and vicinity, Camden County, New Jersey

[NJDEP, New Jersey Department of Environmental Protection; NGVD of 1929, National Geodetic Vertical Datum of 1929; --, data not available]

U.S. Geological Survey well number	Well name	NJDEP permit number	Aquifer code[1]	Altitude of land surface[2] (feet above NGVD of 1929)	Depth of well (in feet below land surface)	Screened interval (in feet below land surface)	
						Top	Bottom
5-1418	PSLF MW-12	31-26580	MRPA	18.24	33	13	33
7-98	CAMDEN DIV 52	31-04847	MRPAL	18	200	147	198
7-109	CAMDEN DIV 46	31-00162	MRPAL	11.3	178	148	178
7-111	CAMDEN DIV 50	31-03456	MRPAL	9	170	139	170
7-113	CAMDEN DIV 27	--	MRPAL	10	135	102	135
7-319	MPWC BROWNING 1	31-05641	MRPA	15	152	132	152
7-320	WOODBINE 1	31-04642	MRPAL	69	285	245	285
7-329	MPWC BROWNING 2	31-04836	MRPA	16	140	110	140
7-332	MARION 2	31-04641	MRPAL	72	258	223	258
7-335	MARION 1	31-02915	MRPAL	61	278	243	278
7-341	DELA GARDEN 2	31-01417	MRPAL	45.3	145	115	145
7-342	DELA GARDEN 1A	31-05228	MRPAL	28	139	109	139
7-345	PARK AVE 5	31-00011	MRPAL	17	288	248	288
7-346	PARK AVE 3A	--	MRPAL	-30	260	210	260
7-348	MPWC PARK AVE 3	31-03534	MRPAL	25	275	240	275
7-349	PARK AVE 1	31-00010	MRPAL	8	270	240	270
7-350	PARK AVE 2	51-00064	MRPAL	12	257	232	257
7-358	PUCHACK 4R/6-70	31-05450	MRPAL	47.5	220	170	220
7-359	PUCHACK 5	51-00059	MRPAL	27.8	208	181	204
7-363	PUCHACK 2	51-00057	MRPAL	13.8	170	124	164
7-366	PUCHACK 1	51-00056	MRPAL	12.2	140	107	137
7-367	PUCHACK 3	51-00058	MRPAL	13.6	176	139	176
7-368	DELAIR 1	51-00053	MRPAL	10	138	106	126
7-369	DELAIR 2	51-00054	MRPAL	5	146	111	141
7-370	DELAIR 3	51-00055	MRPAL	6	132	107	127
7-372	NATIONAL HWY 1	31-05110	MRPAL	68	231	195	230
7-373	MORRIS 6	51-00051	MRPAL	5.9	138	98	133
7-374	MORRIS 9	51-00076	MRPAL	6.8	143	99	118
7-375	MORRIS 8	31-00944	MRPAL	6	128	89	124
7-377	MORRIS 7	51-00052	MRPAL	6	120	85	120
7-379	MORRIS 10	31-04251	MRPAL	8.7	118	75	115
7-382	MORRIS 4A	31-04252	MRPAL	6	134	95	130
7-386	MORRIS 3A	31-00945	MRPAL	10	107	73	103
7-387	MORRIS 2	51-51106	MRPAL	6	123	93	123
7-388	MORRIS 5	--	MRPAL	5	115	80	115
7-390	MORRIS 1	51-00050	MRPAL	6	107	93	118
7-528	PUCHACK 6-75/7	31-08526	MRPAL	20.1	180	140	180
7-530	MPWC PARK AVE 6	31-14564	MRPAL	40	270	240	270
7-535	TW-1-79	31-15367	MRPAL	10.9	132	100	130
7-536	TW-3-79	31-15369	MRPAL	10	117	85	115
7-537	TW-4-79	--	MRPAL	10	128.3	97	128.3
7-538	TW-5-79	--	MRPAL	10	129	80	110
7-540	TW-7-79	31-14569	MRPAL	10	141	98	138
7-545	MORRIS 11	31-15745	MRPAL	15.3	149	102	144
7-547	54	31-18944	MRPAL	35	200	155	195
7-560	WOODBINE 2	31-14563	MRPAL	58	226	196	226
7-568	LANDFILL 1	--	MRPA	24.9	60.0	59	60
7-571	LANDFILL 4	--	MRPA	24.6	48.0	47	48
7-575	BELL IND-1	31-01357	MRPA	40	84	74	84
7-586	MORRIS 12	31-16814	MRPAL	10	122	86	117

Table 1. Well-construction data for wells used in the development and calibration of the Pennsauken ground-water-flow model, Pennsauken Township and vicinity, Camden County, New Jersey—Continued

[NJDEP, New Jersey Department of Environmental Protection; NGVD of 1929, National Geodetic Vertical Datum of 1929; --, data not available]

U.S. Geological Survey well number	Well name	NJDEP permit number	Aquifer code[1]	Altitude of land surface[2] (feet above NGVD of 1929)	Depth of well (in feet below land surface)	Screened interval (in feet below land surface) Top	Bottom
7-587	MORRIS 13	31-16813	MRPAL	10	135	90	130
7-587	MORRIS 13	31-16813	MRPAL	10	135	90	130
7-597	55	31-20270	MRPAL	11	176	136	176
7-602	NATIONAL HWY 2	31-19207	MRPAL	35	206	182	206
7-724	CLEVELAND AVE PW 53	31-18947	MRPAL	32	194	154	194
7-848	BISHOP EUSTACE PREP	31-17884	MRPA	25	150	135	150
7-851	CAMDEN CITY MW-1A	31-37328	MRPAL	73.6	140.9	130.9	140.9
7-852	CAMDEN CITY MW-1B	31-37329	MRPA	73.7	103.8	93.8	103.8
7-853	CAMDEN CITY MW-2A	31-37326	MRPAL	57.4	174	164	174
7-854	CAMDEN CITY MW-2B	31-37327	MRPA	57.2	120	110	120
7-855	CAMDEN CITY MW-4A	31-37359	MRPAL	54.9	202	192	202
7-856	CAMDEN CITY MW-4B	31-37360	MRPA	54.7	86	76	86
7-906	PUCHACK MW-1D	31-51230	MRPAL	38.9	177	162	172
7-907	PUCHACK MW-1S	31-51229	MRPA	38.9	61	51	56
7-908	PUCHACK MW-1M	31-51228	MRPAL	39.0	100	85	95
7-909	PUCHACK MW-2M	31-51226	MRPAL	31.6	103	88	98
7-910	PUCHACK MW-2D	31-51227	MRPAL	30.8	155	140	150
7-911	PUCHACK MW-3M	31-51222	MRPA	78.4	138	128	133
7-912	PUCHACK MW-3D	31-51223	MRPAL	78.8	287	272	282
7-913	PUCHACK MW-4M	31-51224	MRPA	60.6	123	108	118
7-914	PUCHACK MW-4I	31-52598	MRPAL	60.2	201	186	196
7-915	PUCHACK MW-4D	31-51225	MRPAL	60.6	260	245	255
7-916	PUCHACK MW-5M	31-51695	MRPA	35.8	78	63	73
7-917	PUCHACK MW-5I	31-52597	MRPAL	35.5	135	120	130
7-918	PUCHACK MW-5D	31-51696	MRPAL	35.6	190	175	185
7-919	PUCHACK MW-6M	31-51697	MRPA	26.4	74	59	69
7-920	PUCHACK MW-6D	31-51698	MRPAL	26.4	193	178	188
7-921	PUCHACK MW-7D	31-51699	MRPAL	58.2	202	187	197
7-922	PUCHACK MW-7M	31-51700	MRPA	58.0	110.5	95.5	105.5
7-923	PUCHACK MW-8M	31-51702	MRPA	23.7	55	40	50
7-924	PUCHACK MW-8D	31-51701	MRPAL	23.7	165	150	160
7-925	PUCHACK MW-9S	31-51705	MRPA	22.2	49	36	46
7-926	PUCHACK MW-9M	31-51704	MRPA	22.5	70	55	65
7-927	PUCHACK MW-9D	31-51703	MRPAL	23.3	181	166	176
7-928	PUCHACK MW-10M	31-51900	MRPA	43.6	91	76	86
7-929	PUCHACK MW-10D	31-51901	MRPAL	43.6	202	187	197
7-930	PUCHACK MW-12M	31-51906	MRPAL	33.7	170	155	165
7-931	PUCHACK MW-14	31-52706	MRPAL	56.3	133	118	128
7-932	DELA GARDEN R-1	31-43420	MRPAL	28.7	145	125	145
7-933	HOLMAN ENT P-47-D	31-45075	MRPAL	28.4	182	177	182
7-934	HOLMAN ENT P-45-D	31-45076	MRPA	28.5	120	100	120
7-940	SUPER TIRE MW-2D	31-35902	MRPA	36.6	75	55	75
7-943	KING ARTHUR MW-5S	31-36280	MRPA	64.7	91	71	91
7-944	KING ARTHUR MW-5D	31-36279	MRPAL	64.7	140	125	140
7-948	GSM MW-11	31-33572-	MRPA	34.0	63	53	63
7-950	SWOPE OIL GM-8S	31-32304-	MRPA	71	130	110	130

Table 1. Well-construction data for wells used in the development and calibration of the Pennsauken ground-water-flow model, Pennsauken Township and vicinity, Camden County, New Jersey—Continued

[NJDEP, New Jersey Department of Environmental Protection; NGVD of 1929, National Geodetic Vertical Datum of 1929; --, data not available]

U.S. Geological Survey well number	Well name	NJDEP permit number	Aquifer code[1]	Altitude of land surface[2] (feet above NGVD of 1929)	Depth of well (in feet below land surface)	Screened interval (in feet below land surface)	
						Top	Bottom
7-951	SWOPE OIL GM-8D	31-32306-	MRPAL	71.1	205	185	205
7-952	SWOPE OIL GM-7S	31-32304-	MRPA	65.1	130	110	130
7-953	SWOPE OIL GM-7D	31-32305-	MRPAL	64.9	200	180	200
7-954	PSLF MW-7	--	MRPA	71.4	115.1	95.2	115.1
7-955	SWOPE OIL GM-2S	31-29668-	MRPA	61.4	130	110	130
7-956	SWOPE OIL GM-2D	31-29669-	MRPAL	61.4	197	177	197
7-957	PSLF MW-3D	31-26142-	MRPAL	60.6	177	157	177
7-958	PSLF MW-5	31-18183	MRPA	72.3	109.8	89.8	109.8
7-959	PSLF MW-5D	31-26143-	MRPAL	72.0	187	167	187
7-960	PSLF MW-6	31-19602	MRPA	37.4	80.4	60.3	80.4
7-961	PSLF MW-6D	31-26141-	MRPAL	38.4	149	129	149
7-962	PSLF MW-2 REPLACE-	31-17781	MRPA	70.0	100	90	100
7-963	PSLF MW-13	31-29056-	MRPA	17.1	44.2	29.2	44.2
7-964	PSLF MW-11	31-24601-	MRPA	19.0	30	10	30
7-965	PSLF MW-11D	31-26140-	MRPAL	18.7	105	85	105
7-987	G-P GYPSUM CORP 1	--	MRPAL	11	146	117	142
7-1006	PUCHACK MW-12D	31-58576	MRPAL	33.0	265	250	260
7-1007	PUCHACK MW-12S	31-58577	MRPA	33.1	108.6	98.6	108.6
7-1008	PUCHACK MW-30I	31-58582	MRPAL	35.2	160	145	155
7-1009	PUCHACK MW-30D	31-58581	MRPAL	35.3	253.5	248.5	253.5
7-1010	CAMDEN CITY MW-2D	31-58585	MRPAL	57.5	255	240	250
7-1011	PUCHACK MW-13D	31-58578	MRPAL	35.1	227	212	222
7-1012	PUCHACK MW-13I	31-58579	MRPAL	34.8	145	140	145
7-1013	PUCHACK MW-13M	31-58580	MRPA	34.6	95	80	90
7-1014	PUCHACK MW-11D	31-58583	MRPAL	61.9	260	245	255
7-1015	PUCHACK MW-11I	31-58584	MRPAL	61.2	167	157	167
7-1016	PUCHACK MW-6I	31-58637	MRPAL	26.3	117	102	112
7-1018	CAMDEN CITY MW-1D	31-58629	MRPAL	73.6	235	220	230
7-1019	PUCHACK MW-25D	31-58573	MRPAL	42.6	215	205	215
7-1020	PUCHACK MW-25I	31-58574	MRPAL	42.6	154	144	154
7-1021	PUCHACK MW-25M	31-58575	MRPA	42.5	95	80	90
7-1022	PUCHACK MW-19M	31-58628	MRPA	25.4	73	63	73
7-1023	PUCHACK MW-22D	31-58571	MRPAL	23.7	200	190	200
7-1024	PUCHACK MW-22I	31-58572	MRPAL	23.6	115	110	115
7-1025	PUCHACK MW-17D	31-58639	MRPAL	22.2	185	170	180
7-1026	PUCHACK MW-17I	31-58640	MRPAL	22.4	105	90	100
7-1027	PUCHACK MW-19D	31-58626	MRPAL	25.6	163	148	158
7-1028	PUCHACK MW-19I	31-58627	MRPAL	25.5	92	82	92
7-1029	PUCHACK MW-29D	31-59192	MRPAL	40.2	280	265	275
7-1030	PUCHACK MW-29I	31-59193	MRPAL	40.3	175	160	170
7-1031	PUCHACK MW-24I	31-59204	MRPAL	55.2	172	167	172
7-1032	PUCHACK MW-24M	31-59205	MRPA	55.3	103	88	98
7-1033	PUCHACK MW-16D	31-58623	MRPAL	60.0	182	167	177
7-1034	PUCHACK MW-16I	31-58624	MRPAL	59.6	118	108	118
7-1035	PUCHACK MW-16M	31-58625	MRPA	59.4	89	84	89
7-1036	PUCHACK MW-21D	31-58633	MRPAL	20.8	201	186	196
7-1037	PUCHACK MW-21I	31-58634	MRPAL	20.6	107	92	102
7-1038	PUCHACK MW-21M	31-58685	MRPA	20.4	60	50	55
7-1039	PUCHACK MW-18D	31-59203	MRPAL	10	155	140	150
7-1040	PUCHACK MW-29S	31-59619	MRPA	40.3	120	105	115

Table 1. Well-construction data for wells used in the development and calibration of the Pennsauken ground-water-flow model, Pennsauken Township and vicinity, Camden County, New Jersey—Continued

[NJDEP, New Jersey Department of Environmental Protection; NGVD of 1929, National Geodetic Vertical Datum of 1929; --, data not available]

U.S. Geological Survey well number	Well name	NJDEP permit number	Aquifer code[1]	Altitude of land surface[2] (feet above NGVD of 1929)	Depth of well (in feet below land surface)	Screened interval (in feet below land surface)	
						Top	Bottom
7-1042	PUCHACK MW-35D	31-59990	MRPAL	89.2	280	265	275
7-1043	PUCHACK MW-35I	31-59991	MRPAL	88.9	225	210	220
7-1044	PUCHACK MW-12WT	31-59755	MRPA	32.9	80	70	80
7-1045	PUCHACK MW-3I	31-59988	MRPAL	77.6	209	194	204
7-1046	PUCHACK MW-30S	31-59712	MRPA	35.1	100	85	95
7-1047	PUCHACK MW-14	31-59764	MRPAL	58.7	200	190	200
7-1048	PUCHACK MW-34D	31-59809	MRPAL	28.9	233	218	228
7-1049	PUCHACK MW-34I	31-59810	MRPAL	29.0	148	133	143
7-1050	PUCHACK MW-34M	31-59811	MRPA	29.1	68	63	68
7-1051	PUCHACK MW-14D	31-59201	MRPAL	58.2	235	220	230
7-1052	PUCHACK MW-14I	31-59202	MRPAL	58.5	170	165	170
7-1053	PUCHACK MW-26I	31-59894	MRPAL	56.2	129	124	129
7-1054	PUCHACK MW-26M	31-59895	MRPA	56.0	82	77	82
7-1055	PUCHACK MW-27D	31-59303	MRPAL	67.3	220	210	220
7-1056	PUCHACK MW-27I	31-59364	MRPAL	66.9	130	115	125
7-1057	PUCHACK MW-27M	31-59365	MRPA	66.2	83	78	83
7-1058	PUCHACK MW-15D	31-59436	MRPAL	62.7	230	215	225
7-1059	PUCHACK MW-15I	31-59437	MRPAL	63.1	169	164	169
7-1060	PUCHACK MW-15M	31-59438	MRPAL	63.0	145	130	140
7-1061	PUCHACK MW-23D	31-59366	MRPAL	54.0	225	210	220
7-1062	PUCHACK MW-23I	31-59367	MRPAL	54.0	152	147	152
7-1063	PUCHACK MW-23M	31-59368	MRPAL	54.2	123	108	118
7-1064	PUCHACK MW-31D	31-59528	MRPAL	44.6	228	213	223
7-1065	PUCHACK MW-31I	31-59529	MRPAL	44.8	155	140	150
7-1066	PUCHACK MW-31M	31-59530	MRPA	45.0	92	82	92
7-1067	PUCHACK MW-20D	31-59526	MRPAL	19.2	190	175	185
7-1068	PUCHACK MW-20I	31-59527	MRPAL	19.2	94	89	94
7-1069	PUCHACK MW-21S	31-59925	MRPA	32.4	55	45	55
7-1070	MORRIS 14	31-56691	MRPAL	11	125	93	120
7-1071	MORRIS 15	31-57430	MRPAL	12	128	93	123
7-1072	MPWC S-2	31-42230	MRPA	41	74	54	74
7-1073	MPWC L-1	31-42231	MRPAL	35	138	118	138
7-1074	MPWC S-1	31-43423	MRPA	30	57	47	57
7-1075	MPWC P-1	31-43422	MRPAL	28	147	127	147
7-1076	MPWC P-2	31-43421	MRPAL	28	140	120	140
7-1077	MPWC R-2	31-43419	MRPAL	26	145	125	145

[1]Aquifer codes are MRPAM, Middle Potomac-Raritan-Magothy aquifer; MRPAL, Lower Potomac-Raritan-Magothy aquifer.

[2]Values of altitude of land surface listed as whole numbers were determined by visual inspection of a 1:24,000-scale topographic map or by altimeter. Values listed to the tenth place were determined by level measurement.

[3]Denotes the Intermediate sand unit within the Lower Potomac-Raritan-Magothy aquifer.

Table 2. Hydrogeologic framework of the Potomac-Raritan-Magothy aquifer system and corresponding model layers used in the Pennsauken ground-water-flow model and regional hydrogeologic framework as described in previous studies, Pennsauken Township and vicinity, Camden County, New Jersey

Previously described regional framework[1]	Framework used in the Pennsauken ground-water-flow model		
Hydrogeologic unit	Model units	Model-layer designation	Major hydrogeologic unit
Upper aquifer	Aquifer	A-1	Upper aquifer
Confining unit	Confining unit	C-1	Confining unit
Middle aquifer	Upper sand	A-2A	Middle aquifer
	Interbedded confining unit	A-2C1	
	Lower sand	A-2B	
Confining unit	Upper confining unit	C-2A	Confining unit
	Intermediate sand	C-2AI	Lower aquifer
	Lower confining unit	C-2B	
Lower aquifer	Upper zone	A-3A	
	Middle zone	A-3B	
	Lower zone	A-3C	
Bedrock confining unit	Bedrock confining unit		Underlying clay or bedrock

[1]Previously described in Navoy and Carleton (1995); Zapecza (1989); and Farlekas and others (1976).

Aquifer-System Geometry and Model-Grid Design

The hydrogeologic framework as described in Walker and Jacobsen (2004) and Barringer and others (U.S. Geological Survey, written commun, 2003) subdivides the Potomac-Raritan-Magothy aquifer system into layers for use in the ground-water-flow model. The interaction of the Delaware River and the Potomac-Raritan-Magothy aquifer system in the Camden area is described in detail in Navoy and Carleton (1995). The Pennsauken study area described in this report is represented in the model using a finite-difference model grid.

The uppermost unit in this study (A-1) represents the Upper aquifer of the Potomac-Raritan-Magothy aquifer system and generally corresponds to the sands of the Magothy Formation and to overlying Miocene and Pleistocene age deposits. The Upper aquifer is modeled as unconfined in its outcrop area. Where the Upper aquifer is overlain by the Merchantville-Woodbury confining unit, the aquifer is modeled as a confined aquifer.

In this model, the dipping layers that are modeled indicate that all of the units have both unconfined and confined areas. In MODFLOW, only the uppermost layer can be modeled as unconfined (transmissivity varies with water level); therefore, the Upper aquifer is modeled in this manner. All other aquifer and confining-unit layers are modeled as confined units. Where these units crop out, they are modeled, as much as possible, as unconfined units by specifying appropriate recharge, or river boundaries are applied along with storage factors that reflect unconfined conditions (specific yield). The transmissivity in the outcrop areas of these other units is fixed, but the changes in water levels compared to the model unit thicknesses are small; therefore, this result should not be significant.

The confining unit overlying the Middle aquifer is represented using a single model layer (C-1). The Middle aquifer is modeled as two sand units (A-2A and A-2B) and a thin intervening clay (A-2C1). In most areas, the water levels in units A-2A and A-2B in the Middle aquifer are similar.

The confining unit between the Middle and Lower aquifers is represented by three units in this study-- a low permeability layer (C-2A), a sandy unit (C-2AI) referred to as the Intermediate sand in this report, and an underlying layer that ranges from clay to sand (C-2B). Measured water levels in nested wells and data from well logs indicate that the C-2B layer is more permeable than the C-2A layer; however, the movement of chromium into the Intermediate sand near potential source areas indicates local holes are present in the C-2A layer. In areas where the lower unit (C-2B) is more permeable, the Intermediate sand (C-2AI) is in direct connection with the underlying Lower aquifer. The Intermediate sand is important in chromium transport because some of the highest concentrations of chromium were measured in samples from wells screened in this unit.

The Lower aquifer is represented by three sand units in this study (A-3A, A-3B, and A-3C). The three layers allow changes in conductivity observed in the unit from least permeable in the uppermost parts of the aquifer (near confining unit C-2) to most permeable in the deepest part of the aquifer to be represented in the model. The outcrop area of the Lower aquifer, as shown in figure 3, generally coincides with the Delaware River, and the aquifer is in direct contact with riverbed sediments. The lowest of these units, A-3C, represents a permeable gravel that is present throughout much of the model area. The base of the flow system is weathered bedrock or a clay unit overlying the bedrock (C-3).

The flow model consists of 85 rows, 108 columns, and 11 layers. The model grid that was used in the simulation of ground-water flow and the outcrop areas of the major aquifers are shown in figure 2. Cell sizes used in the model range from 206 ft by 219 ft near the Puchack well field to 412 ft by 440 ft at the edge of the model area. The model represents 11 layers, including both aquifers and confining units. The representation of confining units throughout the area and the uniform model grid near the Puchack well field provide the potential for simulation of chromium transport using MOC3D, if needed.

Boundary Conditions

Model-boundary conditions are recharge due to precipitation, interaction with the Delaware River and smaller tributary streams, and specified flow. A schematic diagram showing model layers and boundary conditions is presented in figure 3. Where the aquifers are designated as aquifer outcrop areas, the units are modeled as unconfined by applying recharge and specifying river cells, if necessary, and by adjusting the storage coefficient in the transient model to reflect unconfined conditions.

Recharge

Recharge to the outcrop areas of the aquifer and confining units is input to the model using the MODFLOW recharge package. Recharge is applied to the topmost active cell at any location except in outcrop areas where the Delaware River also is modeled. Recharge zones and rates used in the model are shown in figure 4. Recharge zones are based on generalized land-use categories obtained from the New Jersey Integrated Terrain Unit (ITU) GIS digital data set for 1986 (New Jersey Department of Environmental Protection, 1996). The major land-use categories used to represent variations in ground-water recharge are commercial-industrial, open land, landfill, residential, and filled land. Filled land represents areas where land adjacent to the Delaware River has been filled and built up. These areas are assumed on the basis of field visits to the sites to be relatively impermeable as compared to other areas. Recharge rates (shown below) range from 6 to 14 inches per year, which is consistent with rates used in other model studies throughout the New Jersey Coastal Plain (Navoy and Carleton, 1995; Martin, 1998). The highest recharge rates were assumed to occur in the open-land category; the lowest rates were assigned to the filled land category.

Land use	Recharge rate (in/yr)
Commercial-industrial	10
Open land	14
Landfill	10
Residential	10
Filled land	6

Surface water

The main surface-water body in the area is the Delaware River, and the largest tributary in the modeled area is the Pennsauken Creek. Previous studies (Navoy and Carleton, 1995; and Farlekas and others, 1976) and results of local aquifer tests (Ground Water Associates, 1995b) indicate that the ground-water-flow system in the study area is in contact with the river and that the river contributes appreciable flow to the ground-water-flow system. The Delaware River and tributaries are tidal within the study area with daily fluctuations of about 1 ft. In order to simulate average annual conditions, the river stage in the model was assumed to be 0.5 ft above the NGVD of 1929. for all river cells. Riverbed sediments were assumed to be 10 ft thick in the Delaware River and 3 ft thick in Pennsauken Creek. The zones of riverbed vertical hydraulic conductivity used in this model are the same as those used in the Camden study model (Navoy and Carleton, 1995) (fig 5.). Navoy and Carleton estimated these zones using surface geophysics data (shallow electromagnetic-conductance methods) collected by Duran (1986). Calibrated values of the riverbed hydraulic conductivity used in the model are listed below.

High	2.8 ft/d
Moderate	0.028 ft/d
Low	0.00028 ft/d

The Delaware River and Pennsauken Creek were simulated using the MODFLOW river package. The riverbed conductance at each designated model cell (used as input to the river package in the model) was calculated from the area of the river cell, the bed thickness, and the riverbed hydraulic conductivity.

Lateral model boundaries

The regional flow system around the modeled area is important because of the appreciable use of the Potomac-Raritan-Magothy aquifer system for ground-water supplies in the area. Explicit simulation of the effects of regional ground-water withdrawals would require a larger model area that included

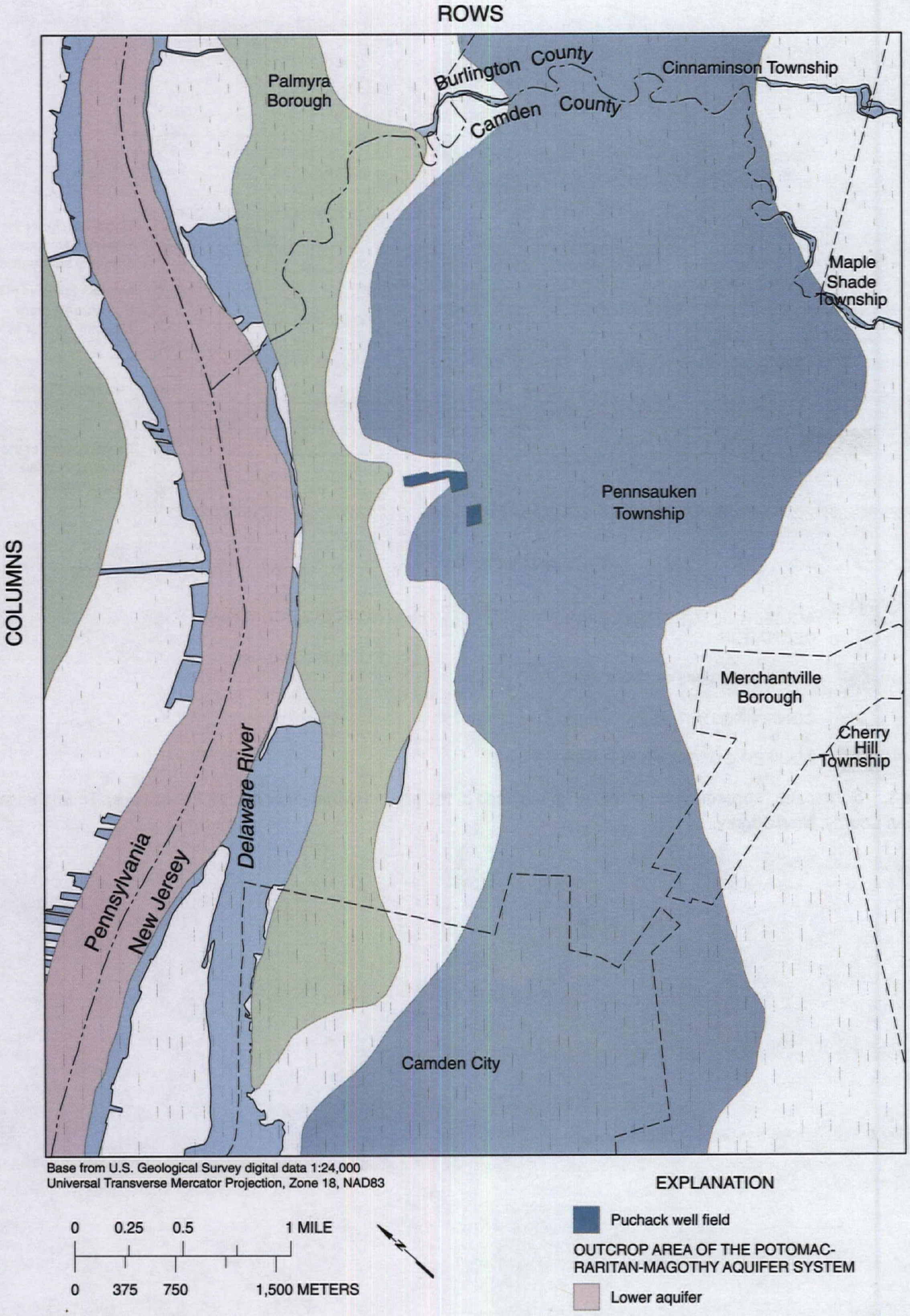

Figure 2. Ground-water-flow model grid and outcrop areas of the Potomac-Raritan-Magothy aquifer system, Pennsauken Township and vicinity, Camden County, New Jersey.

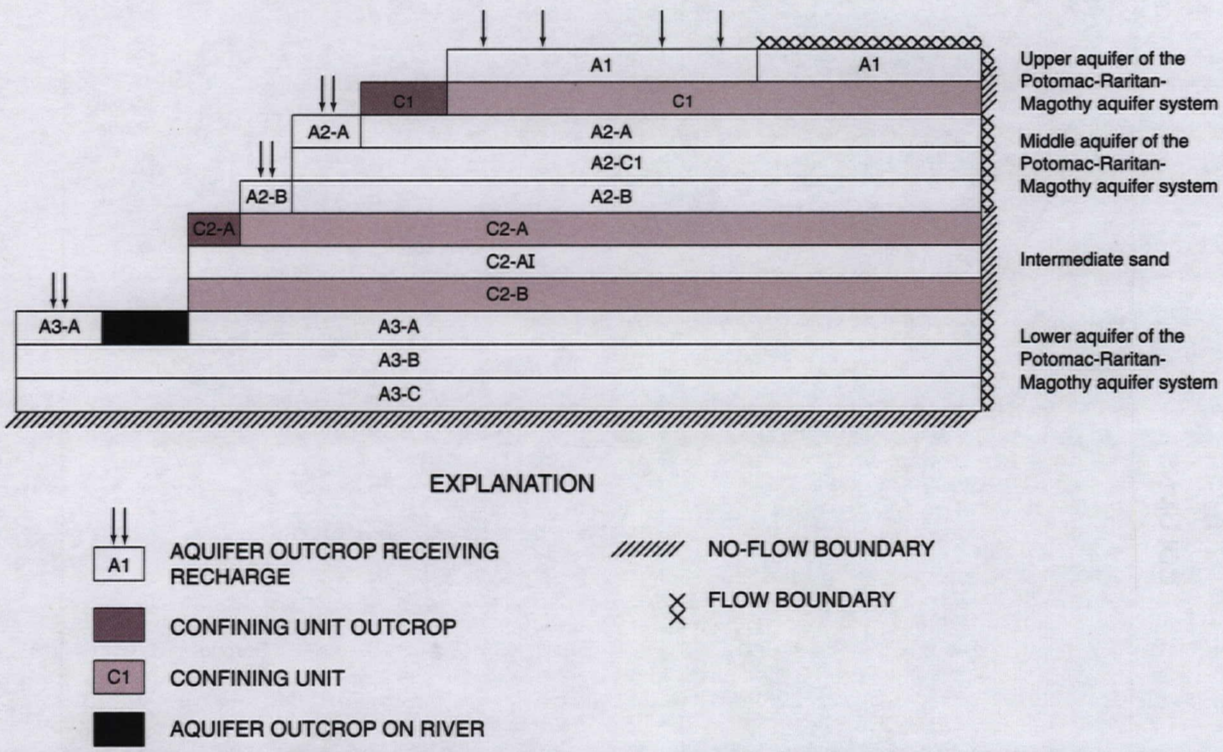

Figure 3. Schematic representation of model layers used in the ground-water-flow model, Pennsauken Township and vicinity, Camden County, New Jersey.

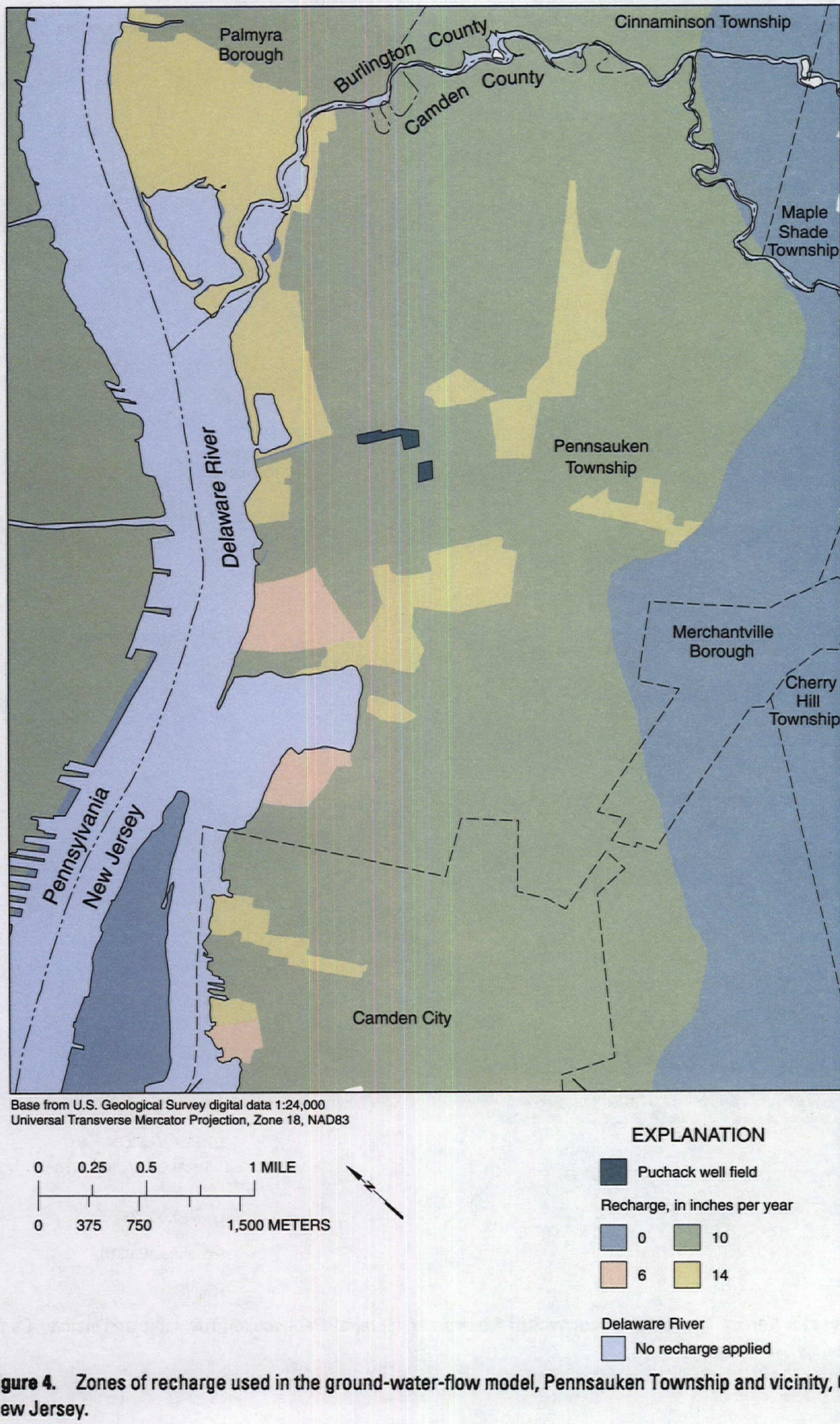

Figure 4. Zones of recharge used in the ground-water-flow model, Pennsauken Township and vicinity, Camden County, New Jersey.

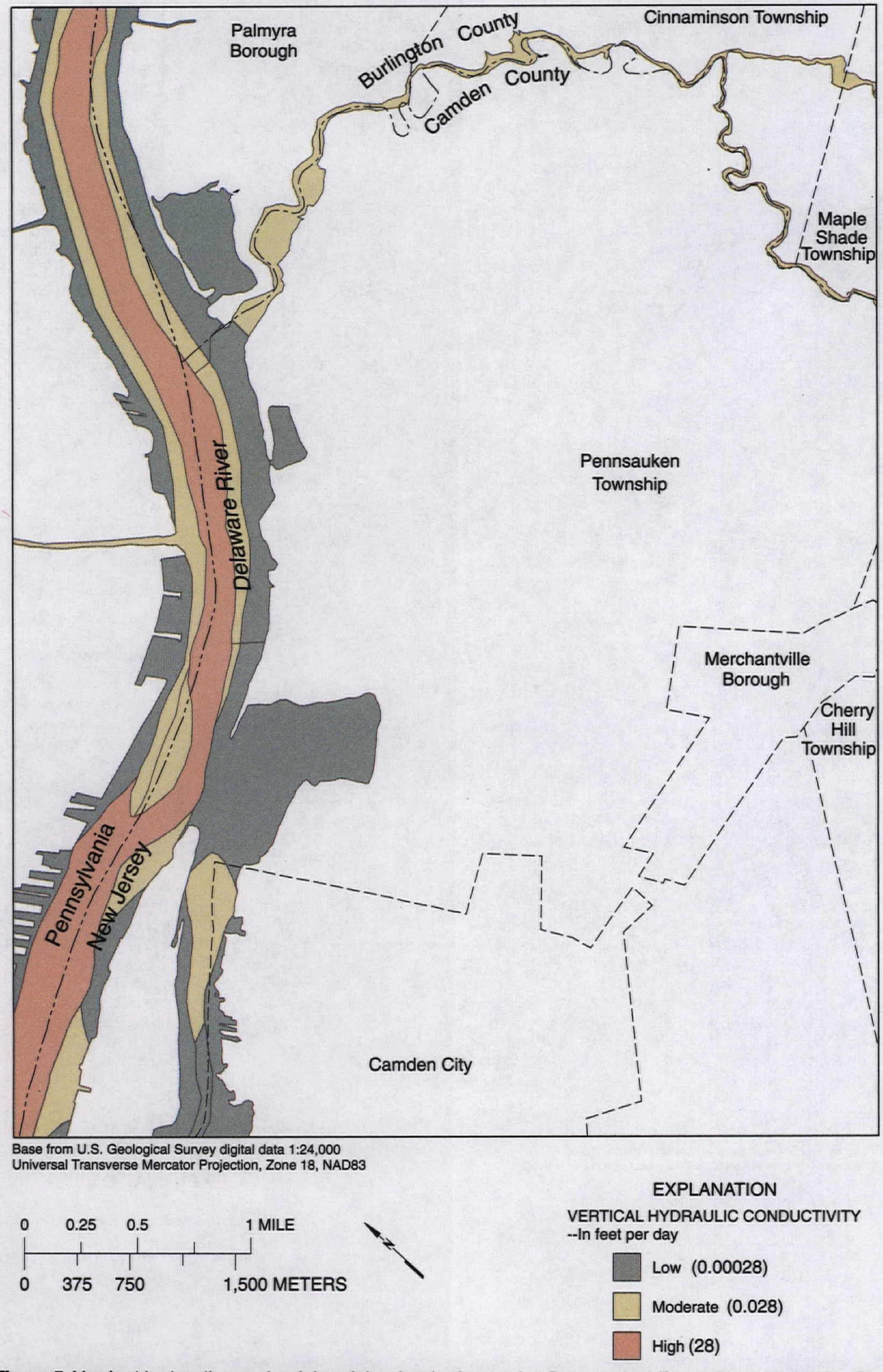

Figure 5. Vertical hydraulic conductivity of the riverbed material, Pennsauken Township and vicinity, Camden County, New Jersey.

hydrologic boundaries and contained regional withdrawal centers. Simulating this larger area was impractical because of the level of detail needed within the Pennsauken area. Therefore, a regional-scale model of the Potomac-Raritan-Magothy aquifer system (Navoy and Carleton, 1995) in Camden County and parts of Burlington and Gloucester Counties provided boundary fluxes for the local model. These fluxes allowed the regional effects that occur outside the model area to be included in the local model.

Boundary flows were assigned only to local model units that represent the Upper aquifer (A-1), the Middle aquifer (A-2A, A-2B) and the Lower aquifer (A-3A, A-3B, and A-3C). Flows were not assigned to the confining unit layers because a quasi-3D approach was used in the regional model, and flow in the confining units was not simulated. Boundary flows from the Upper aquifer in the regional model were assigned to unit A-1. In the Upper aquifer, the fluxes along the lateral and downgradient edges of the local model were important because appreciable flow occurs perpendicular to the local model boundaries near Pennsauken Creek to the north and the Cooper River to the south. Boundary flows in the Middle aquifer from the regional model were divided equally between local model units A-2A and A-2B. Boundary flows in the Lower aquifer from the regional model are divided equally among local model units A-3A, A-3B, and A-3C. Because the water-level contours in the Middle and Lower aquifers along the north and south boundaries generally were perpendicular to the local model boundaries, lateral boundaries in these areas were modeled as no flow boundaries (no fluxes were applied). Along the east/southeast edge of the model, in the Middle and Lower aquifers lateral fluxes were used to represent flows to or from the regional flow system outside the model area.

In order for the regional model to provide accurate boundary fluxes, the regional model-input data had to be consistent with that of the local model. Updates to various model-input data sets were made for the regional model. Withdrawal data for the regional model were updated for each of the periods simulated. During model calibration, the transmissivity of the aquifers and vertical hydraulic conductivity of the confining units in the local model area were updated periodically for the regional model. Riverbed hydraulic conductivity and ground-water recharge rates used in the local model were similar to those used in the regional model so these were not updated for the regional model. After the local model updates were made to the model-input data for the regional model, the regional model was run and results were compared with previous simulations and with measured water levels to ensure that the flow system still was simulated adequately to provide the boundary conditions for the local model.

Ground-Water Withdrawal Data

Ground-water withdrawal data for August 1995, March 1998, April 1998, and April 2001 were obtained from files of the NJDEP Bureau of Water Allocation. In some cases, however, only one value was reported for a well field because the wells were not individually metered at the time of data collection. To provide withdrawal data for each well, the reported withdrawal was divided by the number of wells active at the time. Estimates of reported pump capacities at certain wells also were used to disaggregate the data. Withdrawal data used for each of the model calibration time periods are shown in table 3.

In many cases, the well screens of the public-supply wells cross more than one model layer. To account for this case, the percentage of the well screen in each model layer was estimated and used to calculate the withdrawals for that model layer. Because horizontal hydraulic conductivity values were similar for model layers within the major aquifers (Middle and Lower), this was a reasonable assumption.

Hydrogeologic Properties

Available hydraulic conductivity data from aquifer tests, well acceptance tests, and previous model results were used to assign initial values in the model. Previous model results were used as initial values of vertical hydraulic conductivity of the confining units. These aquifer hydraulic conductivities and confining unit vertical hydraulic conductivities were adjusted during model calibration in order to obtain a good fit to the observed flow system. The calibrated model values of horizontal hydraulic conductivity for the aquifers and vertical hydraulic conductivities for the confining units are described in the following sections. Specific-storage values for the transient simulation of the Delaware Gardens aquifer test also are presented.

Horizontal Hydraulic Conductivity of Aquifers and Confining Units

Calibrated values of horizontal hydraulic conductivity in the Potomac-Raritan-Magothy aquifer system used in the model ranged from 100 to 400 ft/d. The vertical hydraulic conductivity of the aquifer units was assumed to be one-tenth the horizontal hydraulic conductivity to account for bedding planes and laminations within the sediments (Anderson and Woessner, 1991)

The horizontal hydraulic conductivity of the Upper aquifer was set as a uniform value of 100 ft/d. The hydraulic conductivity used in the model for the Middle aquifer (layers A-2A and A-2B) was 200 ft/d. The horizontal hydraulic conductivity of the confining layer (A-2C1) within the Middle aquifer was 15 ft/d.

The three layers in the Lower aquifer consist of permeable sands and gravels with relatively high horizontal hydraulic conductivity (from 300 to 400 ft/d). The two upper layers (A-3A and A-3B) are composed of coarse sands. The lowermost layer in the Lower aquifer (A-3C) also includes a zone of highly conductive sands and gravels. The updip extent of A-3C and the zones of horizontal hydraulic conductivity of the A-3C layer are shown in figure 6. Horizontal hydraulic-conductivity values estimated from specific-capacity data from public-supply wells also are shown in figure 6 and in table 4. These values were obtained from wells completed in all three layers of the Lower

Table 3. Ground-water withdrawal data used in the Pennsauken ground-water-flow model, Pennsauken Township and vicinity, Camden County, New Jersey

[NJDEP, New Jersey Department of Environmental Protection; --, data not available]

U.S. Geological Survey well number	NJDEP well permit number	Well name	Percent of well screen in each model layer: Middle Aquifer	Intermediate sand	Lower Aquifer			Withdrawals, in million gallons per month				Baseline withdrawals (million gallons per year)
			A-2B	C-2AI	A-3A	A-3B	A-3C	August 1995	March 1998	April 1998	April 2001	
City of Camden												
7-368	51-00053	DELAIR 1	0	0	0	60	40	51	31	30	35	231
7-369	51-00054	DELAIR 2	0	0	0	20	80	33	0	0	0	231
7-370	51-00055	DELAIR 3	0	0	15	50	35	27	31	30	0	231
7-390	51-00050	MORRIS 1	0	0	12	88	0	33	31	30	0	231
7-387	51-51106	MORRIS 2	0	0	13	87	0	0	0	0	35	0
7-386	31-00945	MORRIS 3	0	0	70	30	0	3	31	30	35	231
7-382	31-04252	MORRIS 4	0	0	5	95	0	12	31	30	0	231
7-373	51-00051	MORRIS 6	0	0	46	54	0	18	6	6	0	79
7-377	51-00052	MORRIS 7	0	0	57	43	0	43	0	0	0	0
7-375	31-00944	MORRIS 8	0	0	46	54	0	0	26	26	0	231
7-374	51-00076	MORRIS 9	0	0	32	68	0	24	0	0	0	0
7-379	31-04251	MORRIS 10	0	0	60	40	0	40	31	30	35	231
7-545	31-15745	MORRIS 11	0	0	64	36	0	31	0	0	35	231
7-586	31-16814	MORRIS 12	0	0	97	3	0	24	31	30	0	231
7-587	31-16813	MORRIS 13	0	0	65	35	0	53	31	30	0	231
7-1070	31-56691	MORRIS 14	0	0	0	100	0	0	0	0	56	231
7-1071	31-57430	MORRIS 15	0	0	0	100	0	0	0	0	56	231
7-366	51-00056	PUCHACK 1	0	0	70	30	0	54	31	0	0	0
7-363	51-00057	PUCHACK 2	0	0	15	62	23	3	0	0	0	0
Merchantville Pennsauken Water Company												
7-319	31-05641	BROWNING 1	100	0	0	0	0	0	22	21	27	199
7-329	31-04836	BROWNING 2	100	0	0	0	0	24	0	0.7	0	20
7-342	31-05228	DEL. GARDEN	0	0	57	43	0	0	0	0	0	365
7-341	31-01417	DEL. GARDEN	0	0	94	6	0	59	0	0	0	0
7-335	31-02915	MARION 1	0	0	17	63	20	17	0.6	4	4	111
7-332	31-04641	MARION 2	0	0	100	0	0	32	28	23	23	301
7-372	31-05110	NATIONAL	0	0	14	86	0	17	0	0	0	0
7-602	31-19207	NATIONAL	0	0	0	100	0	31	25	23	25	264
7-349	31-00010	PARK AVE 1	0	0	0	47	53	14	13	12	13	151
7-350	51-00064	PARK AVE 2	0	0	24	76	0	14	13	12	13	151
7-348	31-03534	PARK AVE 3	0	0	25	55	20	0	13	12	13	151
7-346	--	PARK AVE 3A	0	0	70	30	0	14	0	0	0	0
7-345	31-00011	PARK AVE 5	0	0	0	40	60	14	13	12	13	151
7-530	31-14564	4R-A/PARK	0	0	87	13	0	14	13	12	0	151
7-320	31-04642	WOODBINE 1	0	0	63	25	12	20	18	17	26	175
7-560	31-14563	WOODBINE 2	0	100	0	0	0	39	34	33	26	332
New Jersey American Water Company												
7-724	31-18947	CLEVELAND	0	0	0	25	75	5	0	0	0	0
7-547	31-18944	54	0	0	0	0	100	7	0	0	0	0
7-597	31-20270	55	0	0	0	58	42	1	0	0	0	0
7-98	31-04847	CAMDEN DIV	0	0	0	100	0	26	0	0	0	0

aquifer. Estimates were made only for wells with a specific-capacity test with a pumping rate of at least 500 gal/min for a minimum of 8 hours. The transmissivity of the aquifer in the vicinity of these wells was estimated from specific-capacity data using the Theis equation as presented in Heath (1983). The horizontal hydraulic conductivity of layers A-3A, A-3B, and that part of A-3C where the gravel unit is not present, was 300 ft/d. The conductivity of the permeable sand-and-gravel parts of the A3-C unit was 400 ft/d. Using these values, the transmissivity of the Lower aquifer (units A3-A, A3-B, and A3-C) ranged from 18,000 to 20,000 ft^2/d in the vicinity of the Delaware Gardens well field where estimates of transmissivity from aquifer tests were available. The transmissivity determined from data collected early in the 72-hour aquifer test at Delaware Gardens well number 1 (Ground Water Associates, 1995a) was 27,000 ft^2/d.

Vertical Hydraulic Conductivity of Confining Units

The vertical hydraulic conductivity values for confining units (C-1, C-2A, and C-2B) were assigned on the basis of geophysical logs and available water-level data to zones that represent similar confining-unit properties. Vertical permeability was classified as "very low", "low", "moderate", "moderately high", "high", or "very high" for each of the confining units. These classifications are specific to each confining unit; a moderate value for one confining unit is not necessarily equivalent to a moderate value for the other confining units. The zones designated as "very high" are areas where the confining unit is not present or is highly permeable as determined on the basis of the geophysical logs.

The calibrated vertical hydraulic conductivity of the confining unit overlying the Middle aquifer (C1) ranged from 0.0002 to 0.05 ft/d (fig. 7). The thin clay layer in the Middle aquifer (A2-C1) was assigned a uniform value of 0.15 ft/d. The calibrated vertical hydraulic conductivity of the confining unit between the Middle aquifer and the Intermediate sand (C-2A) ranged from 0.001 to 0.5 ft/d (fig 8).

The calibrated vertical hydraulic conductivity of the confining unit between the Intermediate sand and the Lower aquifer (C-2B) ranged from 0.15 to 1 ft/d (fig. 9). In general, the vertical hydraulic conductivity of this confining unit was higher than that of confining units C1 or C-2A.

Specific Storage

Storage coefficients used to simulate the Delaware Gardens aquifer test were adjusted so that simulated water levels matched the response of the measured water levels during the test. The storage coefficient for unconfined conditions was set to 0.25 (a typical specific-yield value). For the confined parts of the aquifers, the storage coefficient was 0.00001 . The specific-storage values used in the model were calculated by dividing the storage coefficient values above by the model layer thickness at each grid cell.

Model Calibration

The ground-water-flow model was calibrated using steady-state and transient simulations of ground-water flow. Water-level data and measured changes in water levels due to changing stresses were used in model calibration. Streamflow data were not available to calibrate the model because the Delaware River and its tributaries are tidal in the model area. Flows were calibrated by using known ranges of recharge rates and boundary conditions from the regional model.

Synoptic water-level data collected in March 1998, April 1998, and April 2001 were used to calibrate the flow model. Steady-state simulations of each of these time periods were run. Simulating these periods as steady state is reasonable because of varous factors. In ground-water-flow models throughout the New Jersey Coastal Plain, the confined aquifers respond quickly to changes in stress. The water-level data collected as part of the study of the effects of the shutdown of Puchack well 1 also indicated that the flow system would reach steady state in 3-5 days. Walker (2001) presents water-level data from March and April 1998 and continuous-recorder data from various wells in the vicinity of the Puchack well field. The hydrograph of the Puchack 3a well shows that water-levels recovered within a day or two when Puchack 1 was shut down and that they quickly dropped again when pumping at Puchack 1 resumed. Because the water levels in the vicinity respond to changes in stress within a day or two, it is reasonable to assume that a steady-state simulation would approximate average monthly conditions.

A transient simulation of an aquifer test conducted in August 1995 was compared to aquifer-test results to help quantify the hydraulic connection between the aquifer and the Delaware River and to test model response to changes in withdrawals on a local scale. Steady-state simulations for March 1998 and April 1998 were used to evaluate the changes in head resulting from the shutdown of the Puchack 1 well. Synoptic measurement of water levels throughout the study area was conducted in March 1998. After this round of measurements Puchack 1 was shut down, and water levels in nearby wells were monitored until they stabilized. In April 1998, water levels were measured at a subset of wells located near the Puchack well field to determine how ground-water flow was affected by the shutdown of Puchack 1 (Walker, 2001). The simulated recovery in wells near the Puchack well field was compared to the measured recovery in 22 wells with water-level measurements as part of model calibration. A comparison of the simulated and measured water levels under different flow conditions (withdrawals) provided confidence in the model calibration. The simulated water levels and water levels in wells measured in March 1998 also were compared as part of model calibration.

The observation-well network in the area was expanded as new wells were drilled during 1998-2001. The April 2001 synoptic survey of water levels was an important part of the model calibration because of the additional data made available. Water levels in more wells were available for the potentiometric-surface map and for comparison with simulated water levels. Some

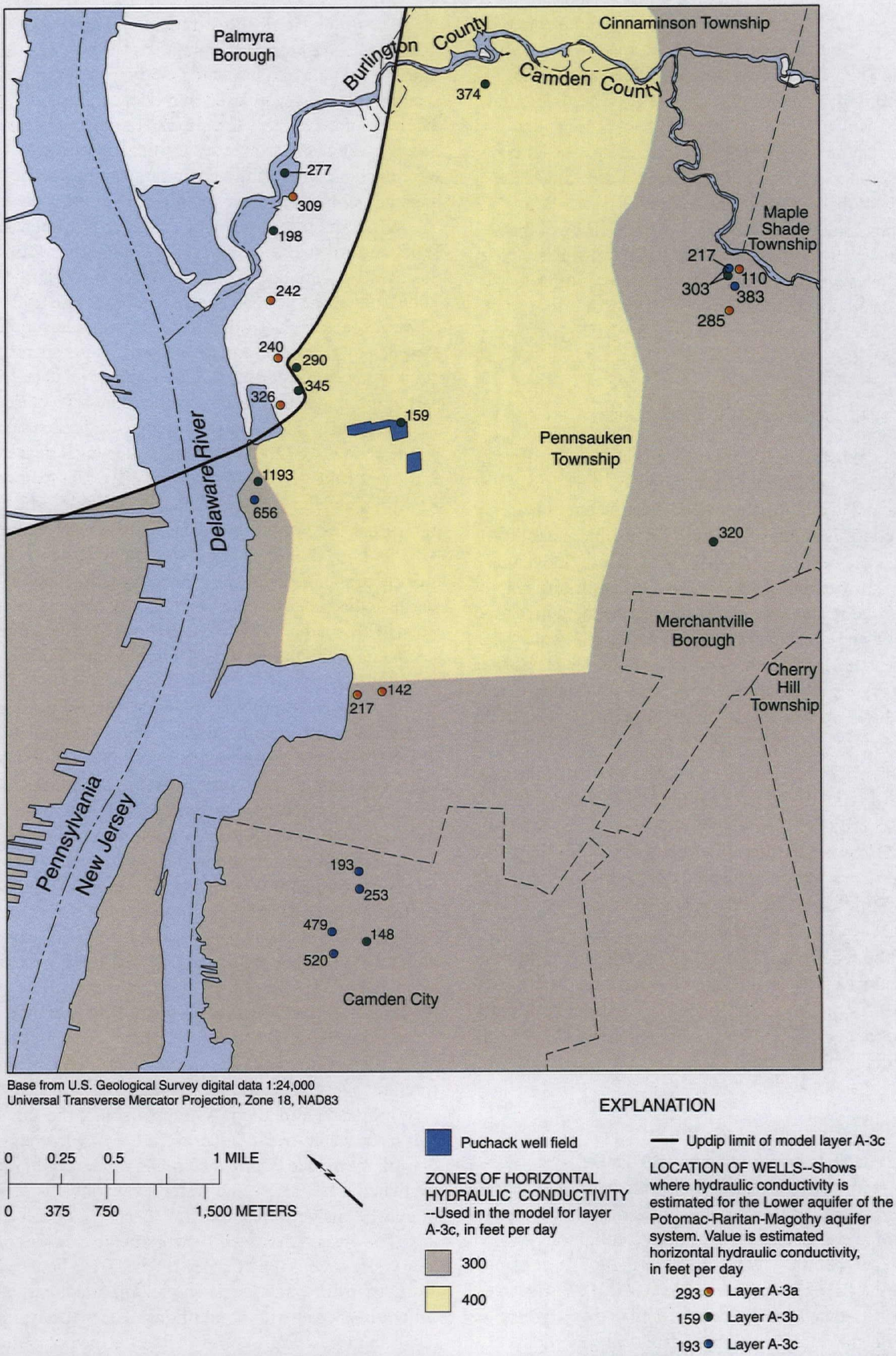

Figure 6. Horizontal hydraulic conductivity of the Lower aquifer of the Potomac-Raritan-Magothy aquifer system in the ground-water-flow model, Pennsauken township and vicinity, Camden County, New Jersey.

Table 4. Estimated horizontal hydraulic conductivity for the Lower aquifer of the Potomac-Raritan-Magothy aquifer system, Pennsauken Township and vicinity, Camden County, New Jersey

[NJDEP, New Jersey Department of Environmental Protection; --, data not available]

U.S. Geological Survey well number	Well name	NJDEP permit number	Depth of well (in feet below land surface)	Well diameter (in inches)	Estimate of hydraulic conductivity (in feet per day)	Length of test (in hours)	Discharge during test (in gallons per minute)
7- 109	CAMDEN DIV 46	31-00162	178	12	520	8	1,400
7- 111	CAMDEN DIV 50	31-03456	170	12	479	8	1,000
7- 325	BROWNING RD 2	31-03987	240	12	293	8	875
7- 332	MARION 2	31-04641	258	12	353	8	1,000
7- 335	MARION 1	31-02915	278	12	320	8	1,020
7- 341	DELA GARDEN 2	31-01417	145	12	217	8	728
7- 342	DELA GARDEN 1A	31-05228	139	12	142	8	882
7- 344	PARK AVE REP 4	--	178	12	360	12	530
7- 345	PARK AVE 5	31-00011	288	12	383	8	1,010
7- 346	PARK AVE 3A	--	260	16	110	24	720
7- 347	PARK AVE 4	--	181	14	306	12	600
7- 348	MPWC PARK AVE 3	31-03534	275	12	303	8	1,030
7- 349	PARK AVE 1	31-00010	270	12	217	8	1,010
7- 350	PARK AVE 2	51-00064	257	12	303	8	1,000
7- 369	DELAIR 2	51-00054	146	26	656	8	1,330
7- 370	DELAIR 3	51-00055	132	26	1,193	8	1,850
7- 373	MORRIS 6	51-00051	138	26	345	8	1,700
7- 374	MORRIS 9/9N	51-00076	143	26	290	8	1,900
7- 377	MORRIS 7	51-00052	120	26	240	8	1,680
7- 379	MORRIS 10	31-04251	118	18	242	8	1,450
7- 382	MORRIS 4A	31-04252	134	18	198	8	1,590
7- 386	MORRIS 3A	31-00945	107	18	309	8	1,000
7- 388	MORRIS 5	--	115	26	277	8	1,630
7- 528	PUCHACK 6-75/7	31-08526	180	18	159	8	1,290
7- 530	4R-A/PARK AVE 6	31-14564	270	18	285	8	1,520
7- 545	MORRIS 11	31-15745	149	16	326	24	2,030
7- 547	54	31-18944	200	16	193	24	1,210
7- 597	55	31-20270	176	16	148	24	1,120
7- 602	NATIONAL HWY 2	31-19207	206	12	374	8	1,240
7- 724	CLEVELAND AVE PW 53	31-18947	194	16	253	24	1,210

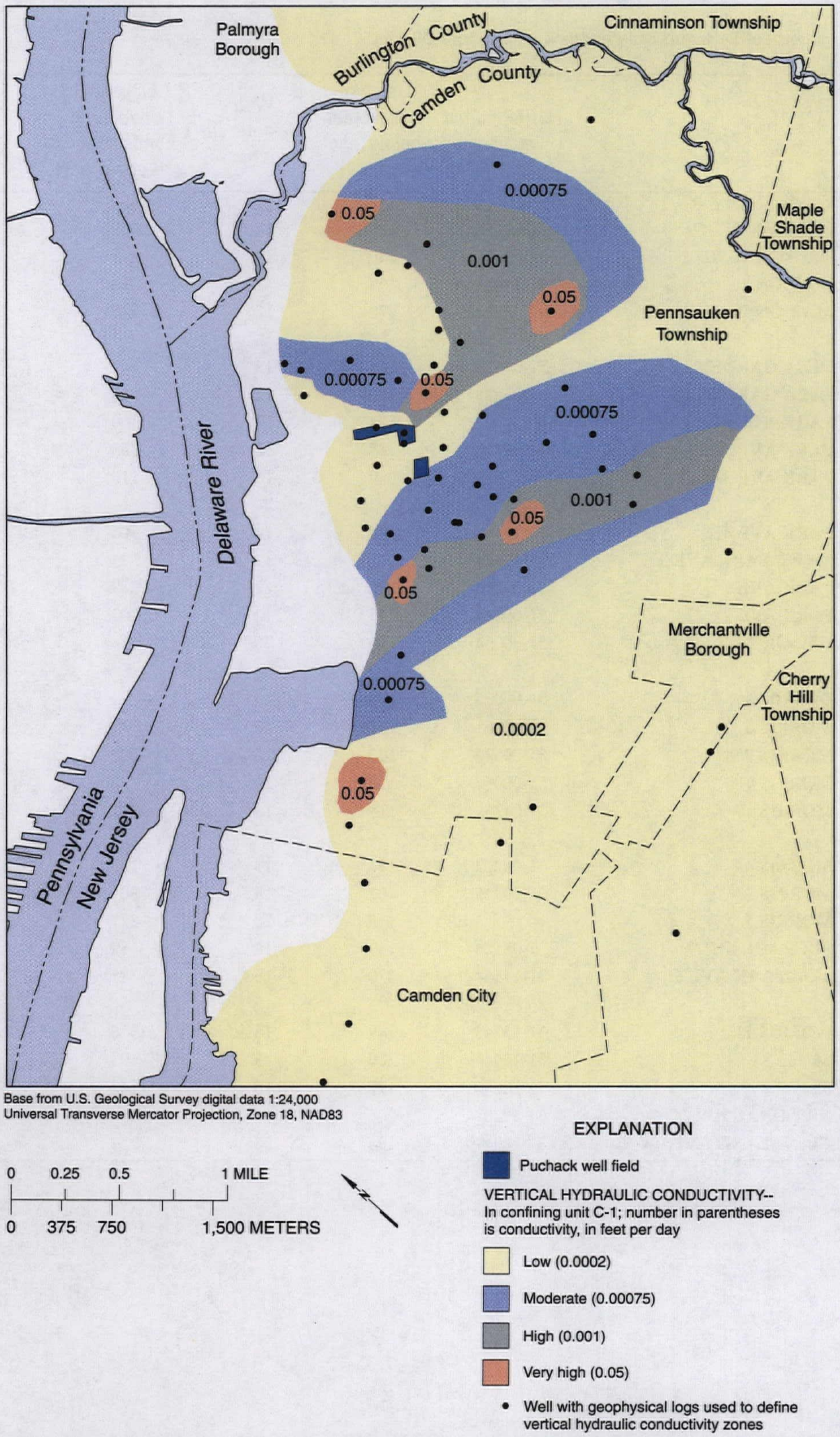

Figure 7. Zones of vertical hydraulic conductivity in confining unit C-1 (between the Upper and Middle aquifers of the Potomac-Raritan-Magothy aquifer system) in the ground-water-flow model, Pennsauken Township and vicinity, Camden County, New Jersey.

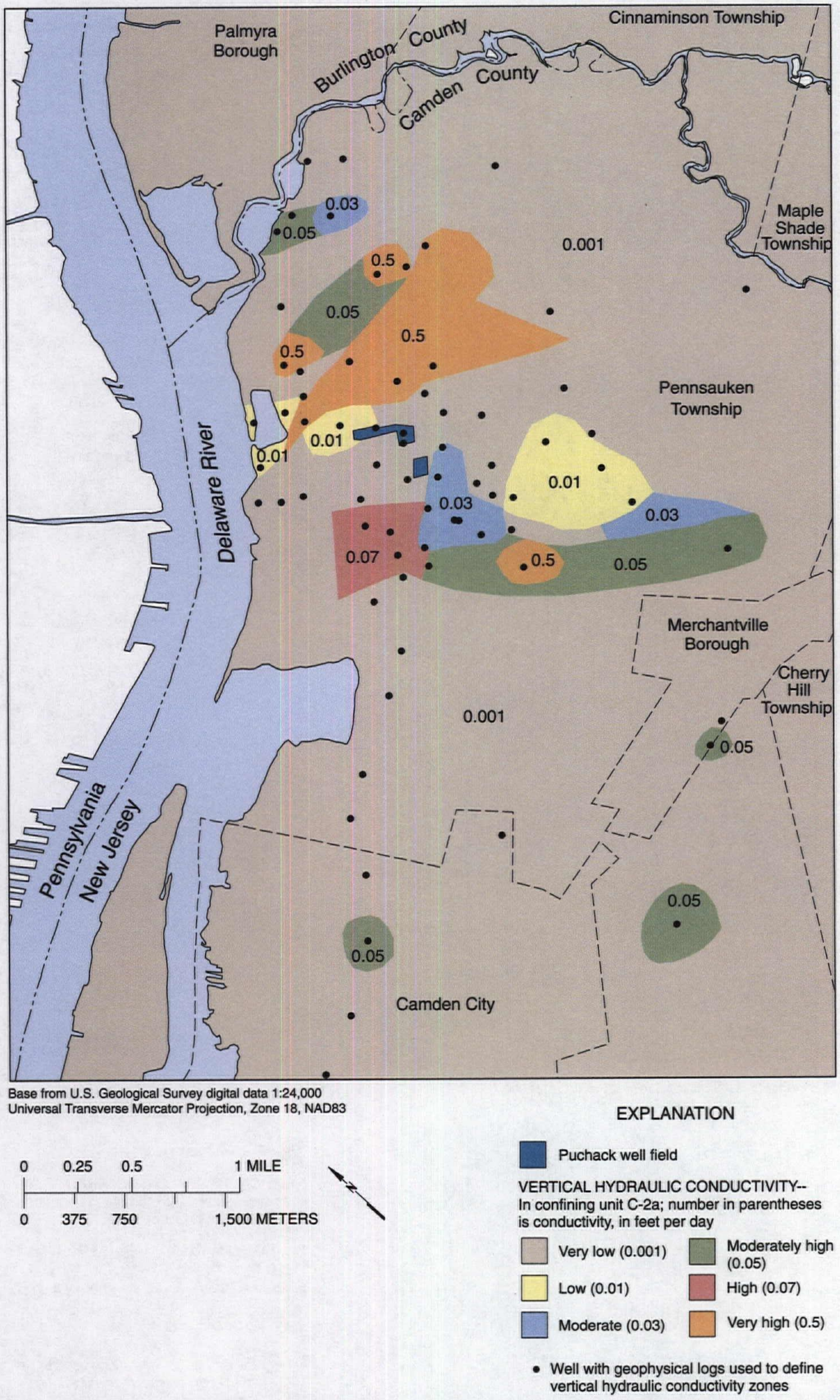

Figure 8. Zones of vertical hydraulic conductivity in confining unit C-2A (between the Middle aquifer of the Potomac-Raritan-Magothy aquifer system and the Intermediate sand) in the ground-water-flow model, Pennsauken Township and vicinity, Camden County, New Jersey.

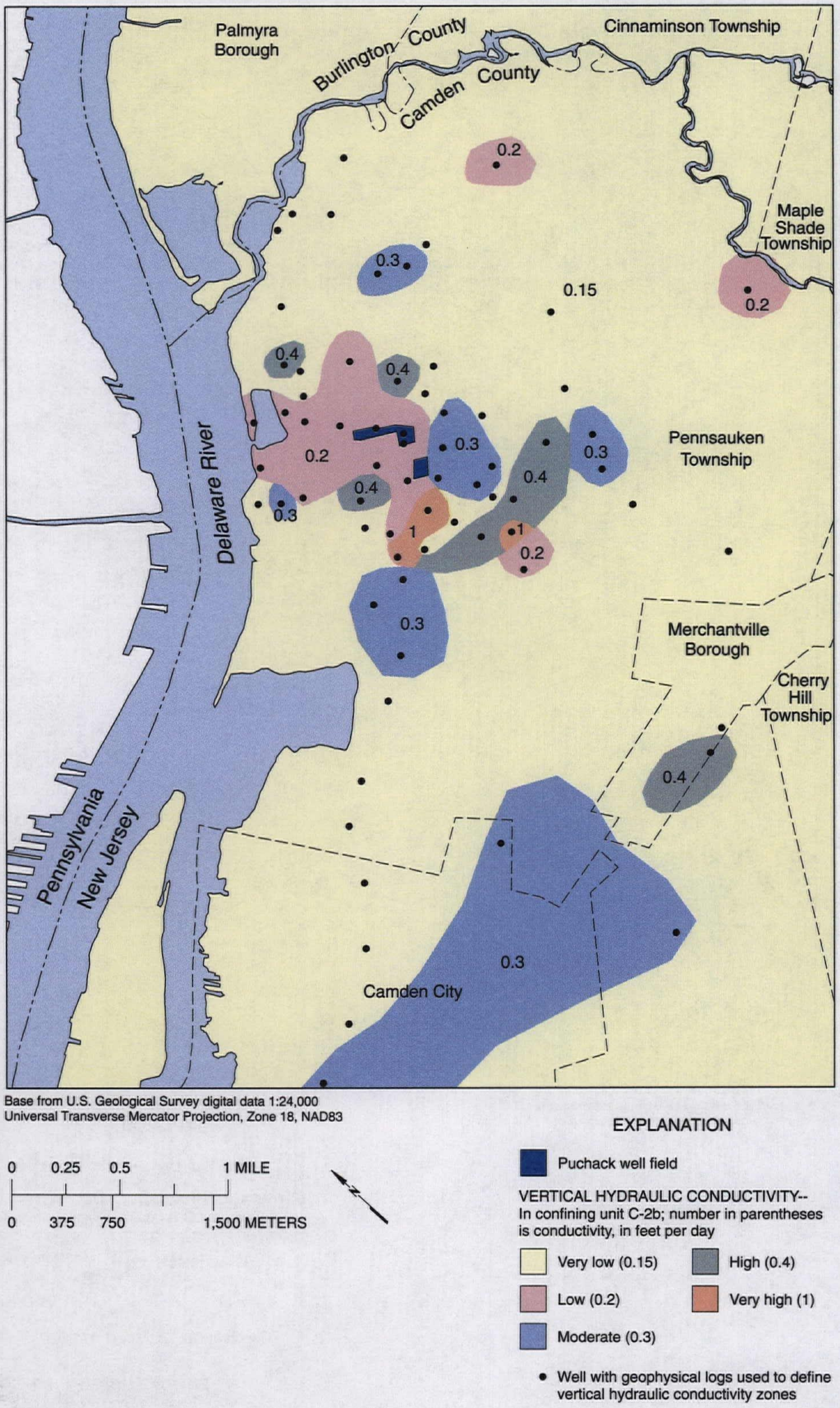

Figure 9. Zones of vertical hydraulic conductivity in confining unit C-2B (between the Intermediate sand and the Lower aquifer of the Potomac-Raritan-Magothy aquifer system) in the ground-water-flow model, Pennsauken Township and vicinity, Camden County, New Jersey.

new nested wells (wells drilled at the same location and completed in different aquifers) were important additions to the observation-well network; simulated and measured water levels across confining units (primarily units C-2A and C-2B) were compared during model calibration. These data were important in the calibration of the vertical hydraulic conductivity of the confining units. The locations of the nested wells are shown on figure 10.

The simulation of the Delaware Gardens aquifer test was conducted to improve the calibration of the vertical hydraulic conductivity of the sediments underlying the Delaware River and to test the capacity of the model to simulate changing flow conditions. The simulated response to pumping the Delaware Gardens well was compared to measured water levels at five observation wells and at the pumped well. Simulated and measured drawdowns were compared at seven observation wells and at the pumped well throughout the test. The data were used primarily to adjust riverbed hydraulic conductivities and storage properties of the aquifer units.

Calibration Criteria

Prior to model calibration, criteria were established to evaluate the simulation results in relation to measured data. These criteria generally involve (1) comparing measured water levels or drawdowns at wells with simulated values (comparing residuals), (2) comparing water-level differences at nested observation wells with simulated water-level differences, and (3) ensuring that the flow budget and model input data are reasonable.

For the calibration to March 1998 and April 2001 conditions, simulated water levels were compared to measured water levels in wells at the same location. The observation package of MODFLOW2000 was used to do a 2-dimensional horizontal interpolatation of simulated values from model cell centers to observation well locations using simulated water levels in the cell containing the well and two adjacent cells. The calibration criterion used for water levels is dependent on the type of well measured. The goal for observation wells drilled as part of this study (which are located primarily in the center of the model grid area near the chromium plume) or other wells where the surveyed land-surface altitude data were available was that the simulated water levels be within +/- 2 ft of the measured water levels (133 wells with surveyed altitude were measured). The calibration criterion for other non-pumped wells used in the calibration was that the simulated water levels be within +/- 5 ft of the measured water levels (15 wells with non-surveyed altitude were measured). The greater range for these wells is appropriate because the altitudes at these wells are not accurately known, and these wells generally are farther away from the chromium plume. Finally, a calibration criterion of +/- 10 ft was used for pumped wells (10 pumped wells were measured).

After model calibration, summary statistics on the difference between simulated and measured water levels were calculated to give an overall indication of the quality of the calibration. The mean average error (MAE), the root mean squared error (RMSE), and the mean error (ME) are common ways to express the average difference between simulated and measured water levels (Anderson and Woessner, 1991). The MAE is the mean of the absolute value of the differences (simulated – measured). The RMSE is the square root of the average of the squared differences (simulated water level – measured water level).

The model response to the shutdown of Puchack 1 in March 1998 also was used as a calibration target. Water levels were measured during March 23-30, 1998, when Puchack 1 was pumped. Puchack 1 was shut down on April 4, 1998, and water levels were measured again on April 7 after water levels recovered. At wells measured in both March 1998 and April 1998, the simulated recovery was compared to the measured recovery. The goal was that the simulated recovery would be within +/- 1 ft of the measured recovery at each well.

The water-level difference across confining units also was used to help calibrate confining unit vertical hydraulic conductivities. At locations where multiple wells screened in different units (nested wells) were available, the simulated and measured vertical differences in water levels were calculated. The goal was that the simulated difference in water levels be within +/- 1 ft of the measured water-level difference at each well nest.

Simulation of March 1998 Conditions

The first model calibration target was the set of water levels measured in March 1998. Withdrawal data for March 1998 are shown in table 3 and figure 11. During March 1998, Puchack 1 was pumped at an estimated rate of 1 Mgal/d.

The simulated potentiometric surfaces of the Middle and Lower aquifers in March 1998 are shown in figures 12 and 13, respectively. Near the Puchack well field, the simulated water levels for observation wells generally were within 3 ft of the measured water levels in both aquifers. Residuals in the area north of the Puchack well field were outside the calibration criterion and ranged from 8.9 ft to -13.5 ft in the Middle aquifer (fig. 12). In the Lower aquifer (fig. 13), residuals were larger in areas away from the Puchack well field near withdrawal wells. The calibration statistics (RMSE, MAE, and ME) for the March 1998 calibration are shown in table 5. All three calibration statistics are lower for the surveyed wells than for the non-surveyed wells.

The mean error is 2.2 ft for all water-level measurements for all aquifers and 3.0 ft for the Lower aquifer. The simulated water levels were high for March 1998, except at a few wells northeast of the Puchack well field near Pennsauken Creek. The ME's for wells in the Lower aquifer (3.0 ft) were higher than those for wells in the Middle aquifer (1.7 ft) and the Intermediate sand (1.9 ft). Simulated water levels in the vicinity of the Puchack well field in the Middle aqufier, Intermediate sand, and Lower aquifer ranged from 1 to 3.5 ft higher than measured water levels at surveyed wells. Residuals at many wells in the vicinity of the Puchack well field were outside the +/- 2 ft range established as a calibration criterion for surveyed wells.

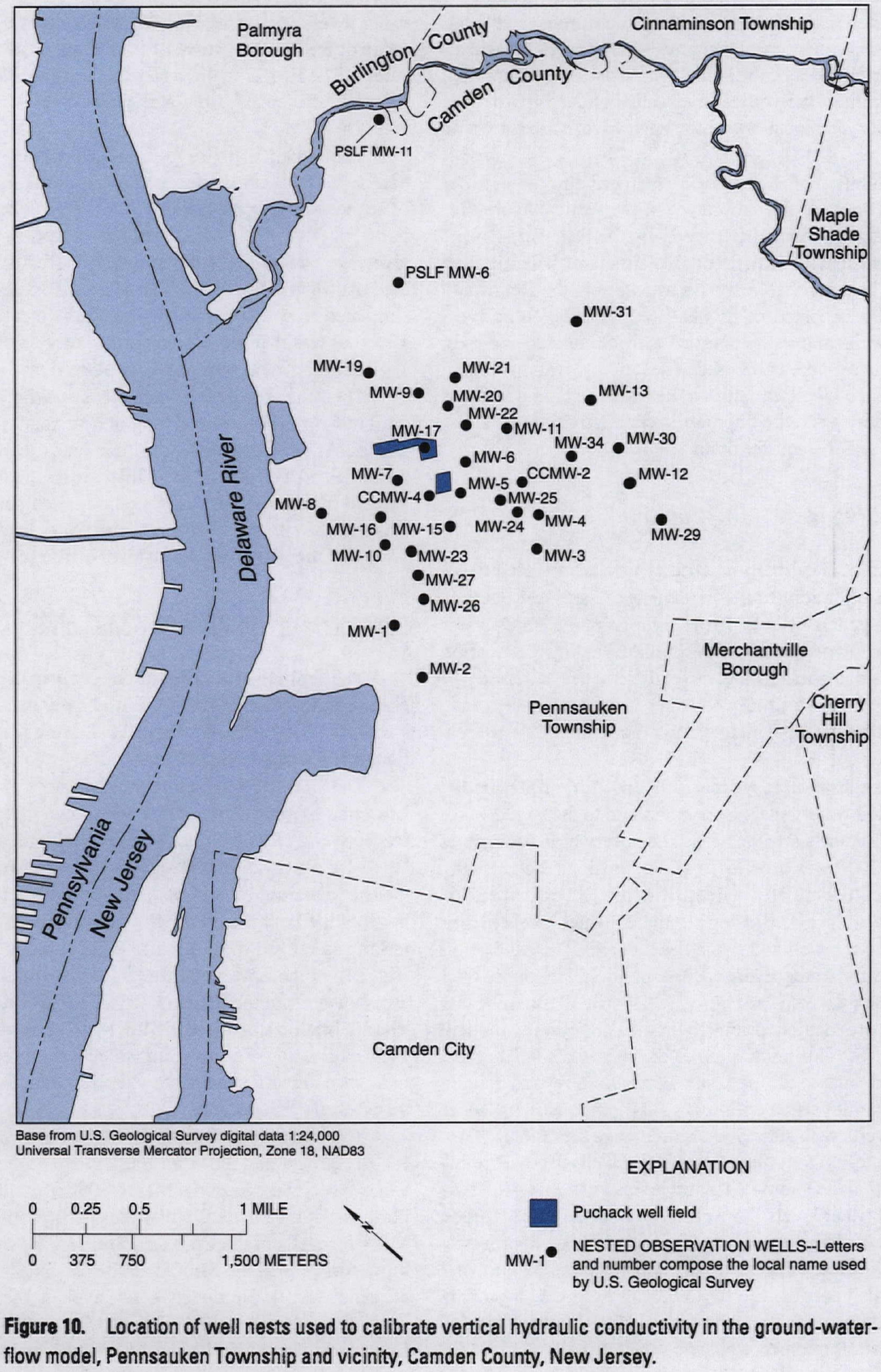

Figure 10. Location of well nests used to calibrate vertical hydraulic conductivity in the ground-water-flow model, Pennsauken Township and vicinity, Camden County, New Jersey.

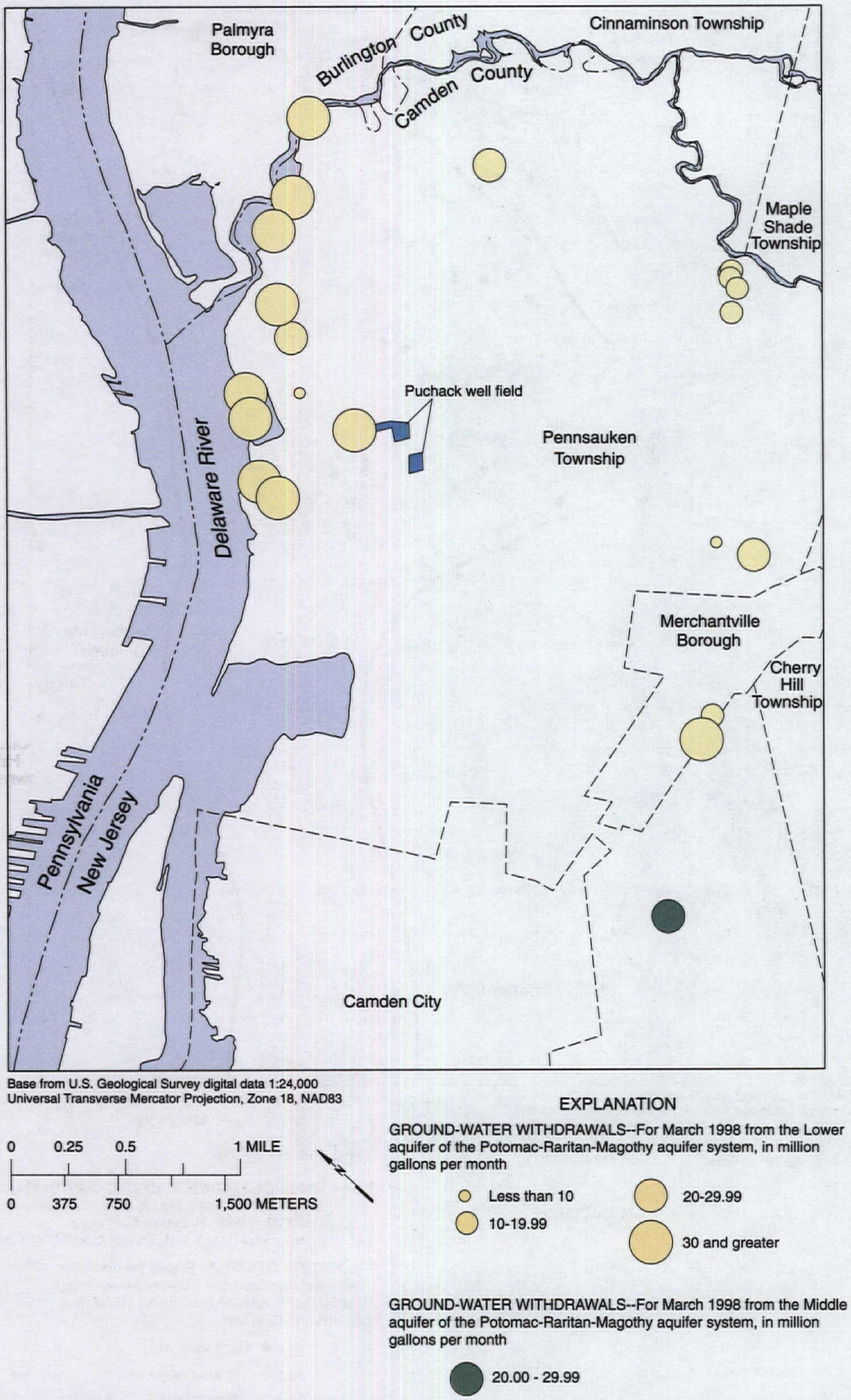

Figure 11. Ground-water withdrawals from the Middle and Lower aquifers of the Potomac-Raritan-Magothy aquifer system, Pennsauken Township and vicinity, Camden County, New Jersey, March 1998.

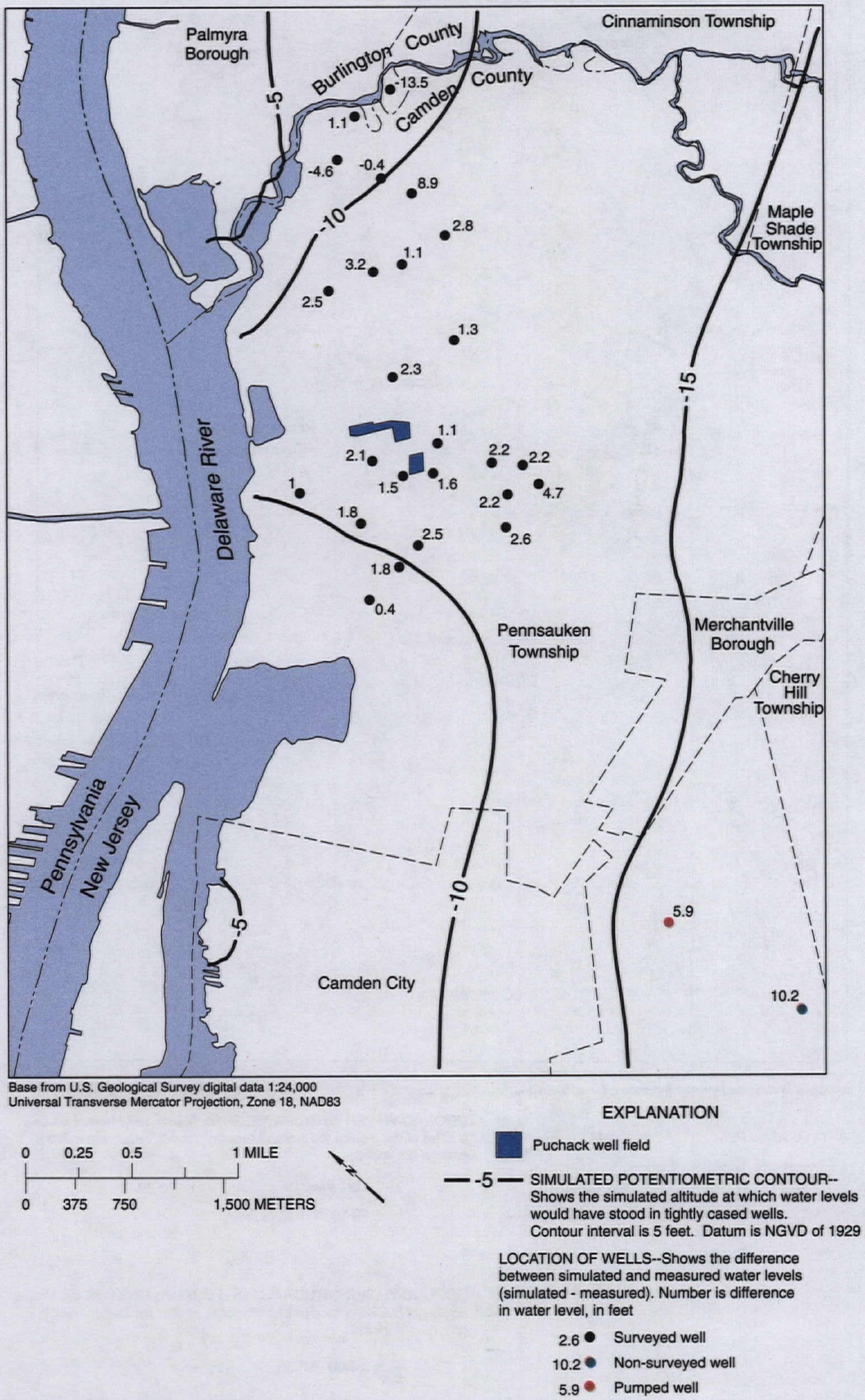

Figure 12. Simulated potentiometric surface and residuals of the Middle aquifer of the Potomac-Raritan-Magothy aquifer system, Pennsauken Township and vicinity, Camden County, New Jersey, March 1998.

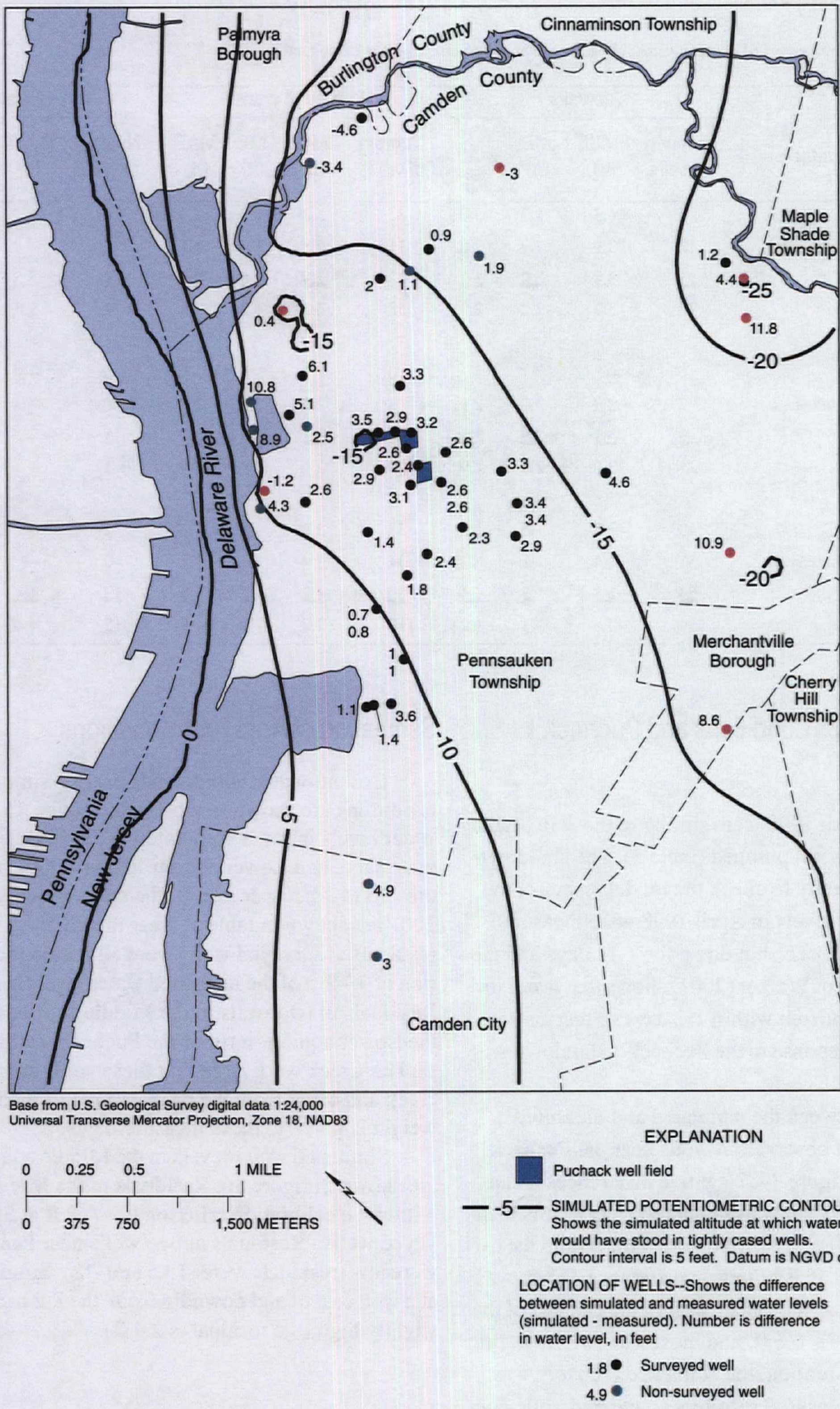

Figure 13. Simulated potentiometric surface and residuals of the Lower aquifer of the Potomac-Raritan-Magothy aquifer system, Pennsauken Township and vicinity, Camden County, New Jersey, March 1998.

Table 5. Root mean squared and mean absolute errors for steady-state water levels in wells completed in the Potomac-Raritan-Magothy aquifer system, Pennsauken Township and vicinity, Camden County, New Jersey

[RMSE, root mean squared error; ME, mean error; MAE, mean absolute error; --, not calculated]

		All wells				Surveyed wells				Non-surveyed wells			
Calibration period	Aquifer	Number of wells	RMSE (ft)	ME (ft)	MAE (ft)	Number of wells	RMSE (ft)	ME (ft)	MAE (ft)	Number of wells	RMSE (ft)	ME (ft)	MAE (ft)
March 1998	Middle	27	4.3	1.7	3.0	25	3.8	1.2	2.7	2	--	--	--
	Intermediate sand	12	2.9	1.9	2.6	11	2.8	1.7	2.5	1	--	--	--
	Lower	31	3.8	3.0	3.2	22	2.9	2.6	2.6	9	5.5	3.8	4.5
	All wells	70	3.7	2.2	2.9	58	3.2	1.8	2.6	12	5.5	3.8	4.5
April 1998	Middle	0	--		--	0	--		--	0	--	--	--
	Intermediate sand	2	2.9	2.9	2.9	2	2.9	2.9	2.9	0	--	--	--
	Lower	19	3.1	2.9	2.9	18	3.1	2.9	2.9	1	--	--	--
	All wells	21	3.0	2.9	2.9	20	3.0	2.9	2.9	1	--	--	--
April 2001	Middle	40	3.5	-.5	1.5	38	3.4	-.8	1.3	2	--	--	--
	Intermediate sand	31	1.4	-.1	.7	31	1.4	-.1	.7	0	--	--	--
	Lower	63	2.3	.3	1.4	50	1.2	.2	.8	13	4.4	.8	3.7
	All wells	134	2.4	-.1	1.2	119	2.0	-.2	.9	15	4.4	.8	3.7

Simulation of April 1998 Conditions and Puchack 1 Shutdown

Withdrawals in April 1998 were similar to those in March 1998, but Puchack 1 was not pumped (table 3). The shutdown provided a good opportunity to check the model response to changes in flows. Water levels in April 1998 were measured after Puchack well 1 had been shut down for 7-14 days and the water levels had stabilized. Walker (2001) shows that water levels at Puchack 3 had stabilized within 1-2 days so that a steady-state simulation of the response to the Puchack 1 shutdown was acceptable.

The differences between the simulated and measured water-level recoveries at observation wells near the Puchack well field are shown in figure 14. Negative differences mean that the simulation did not show as much recovery at this location as was measured. All of the differences were within the calibration criterion of +/- 1 ft. The largest difference, 0.8 ft, was at an observation well near the Delair well field. The rest of the differences were within +/- 0.6 ft, and most were within 0.2 ft. During initial model calibration, the simulated recovery was much greater than the measured recovery so the hydraulic conductivities of the Middle aquifer, Intermediate sand, and Lower aquifer were adjusted during calibration to improve this fit. The calibration statistics for April 1998 are shown in table 5.

Simulation of April 2001 Conditions

Ground-water withdrawals used to simulate April 2001 conditions are shown in table 3 and figure 15. The simulated water levels in wells completed in the Middle aquifer, Intermediate sand, and Lower aquifer in April 2001 are shown in figures 16 to 18, respectively. The calibration statistics for April 2001 are shown in table 5. Near the Puchack well field, the residuals at surveyed wells were all within the calibration criterion of +/- 2 ft of the measured water levels in all three aquifers. Residuals in two wells in the Middle aquifer and two wells in the Lower aquifer north of the Puchack well field along Pennsauken Creek were large, but these wells are adjacent to the creek and away from the primary area of interest so lesser weight is given to these measurements.

Simulated water levels in the Middle aquifer in April 2001 are shown in figure 16. Residuals in the Middle aquifer were within the calibration criterion of +/- 2 ft at 35 of the 38 surveyed wells. Residuals at two wells near Pennsauken Creek were low (residuals were -13.5 and -15). Simulated water levels at a well east of and downdip from the Puchack well field were slightly high (the residual is 2.4 ft).

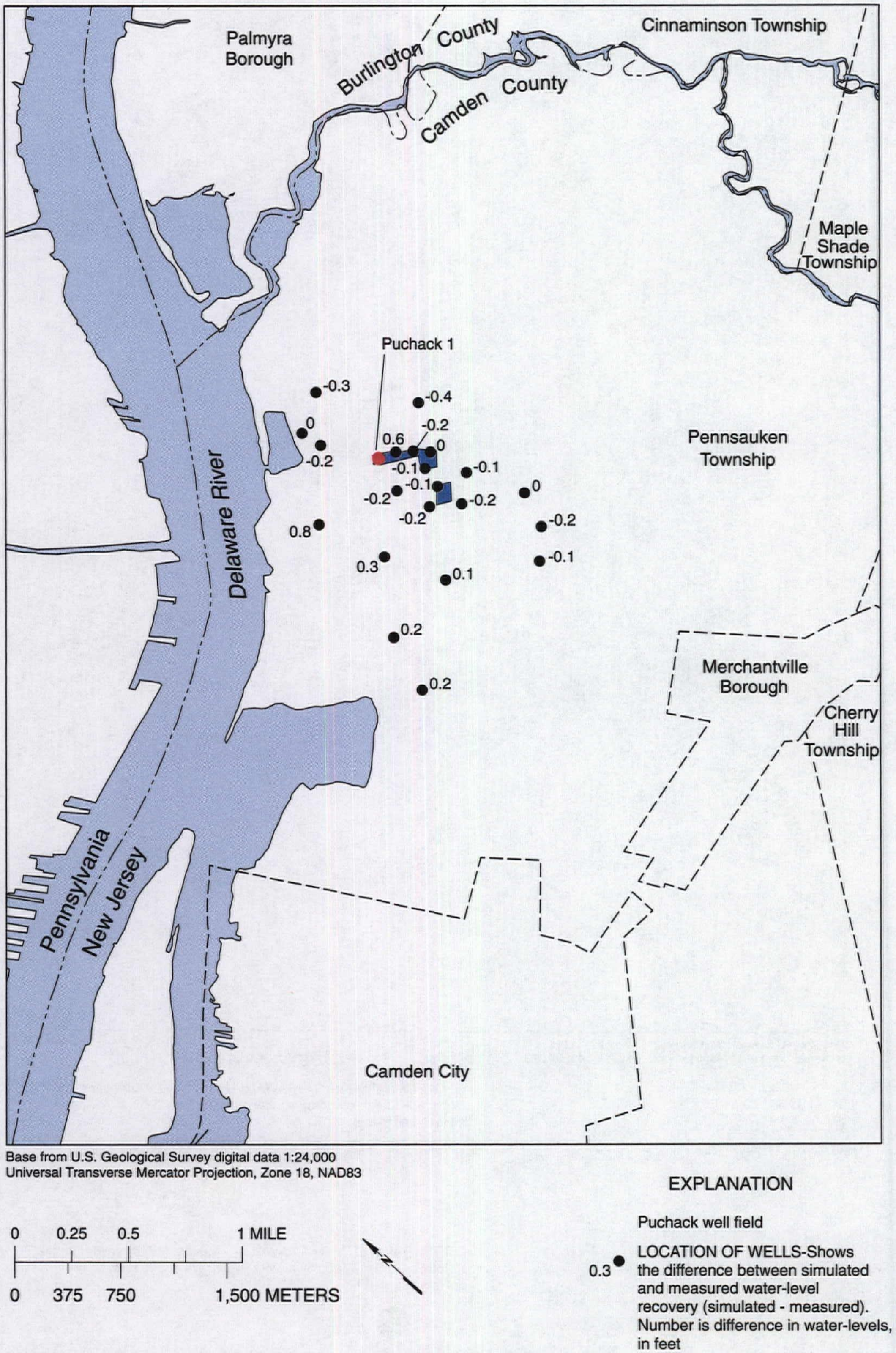

Figure 14. Difference between simulated and measured water-level recovery at wells in the Lower aquifer of the Potomac-Raritan-Magothy aquifer system or the Intermediate sand when Puchack 1 was shut off, Pennsauken Township and vicinity, Camden County, New Jersey.

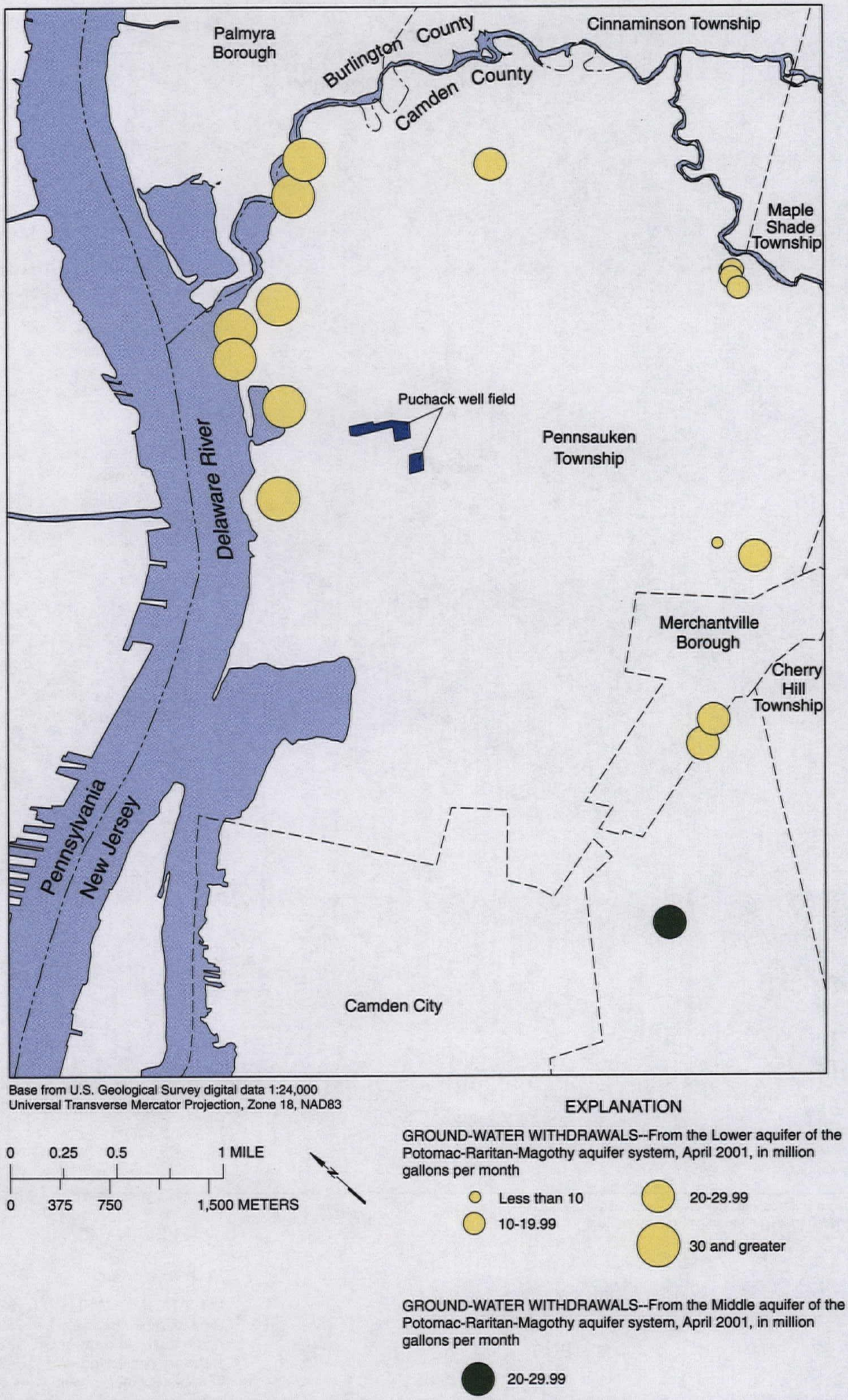

Figure 15. Ground-water withdrawals from the Lower aquifer of the Potomac-Raritan-Magothy aquifer system, Pennsauken Township and vicinity, Camden County, New Jersey, April 2001.

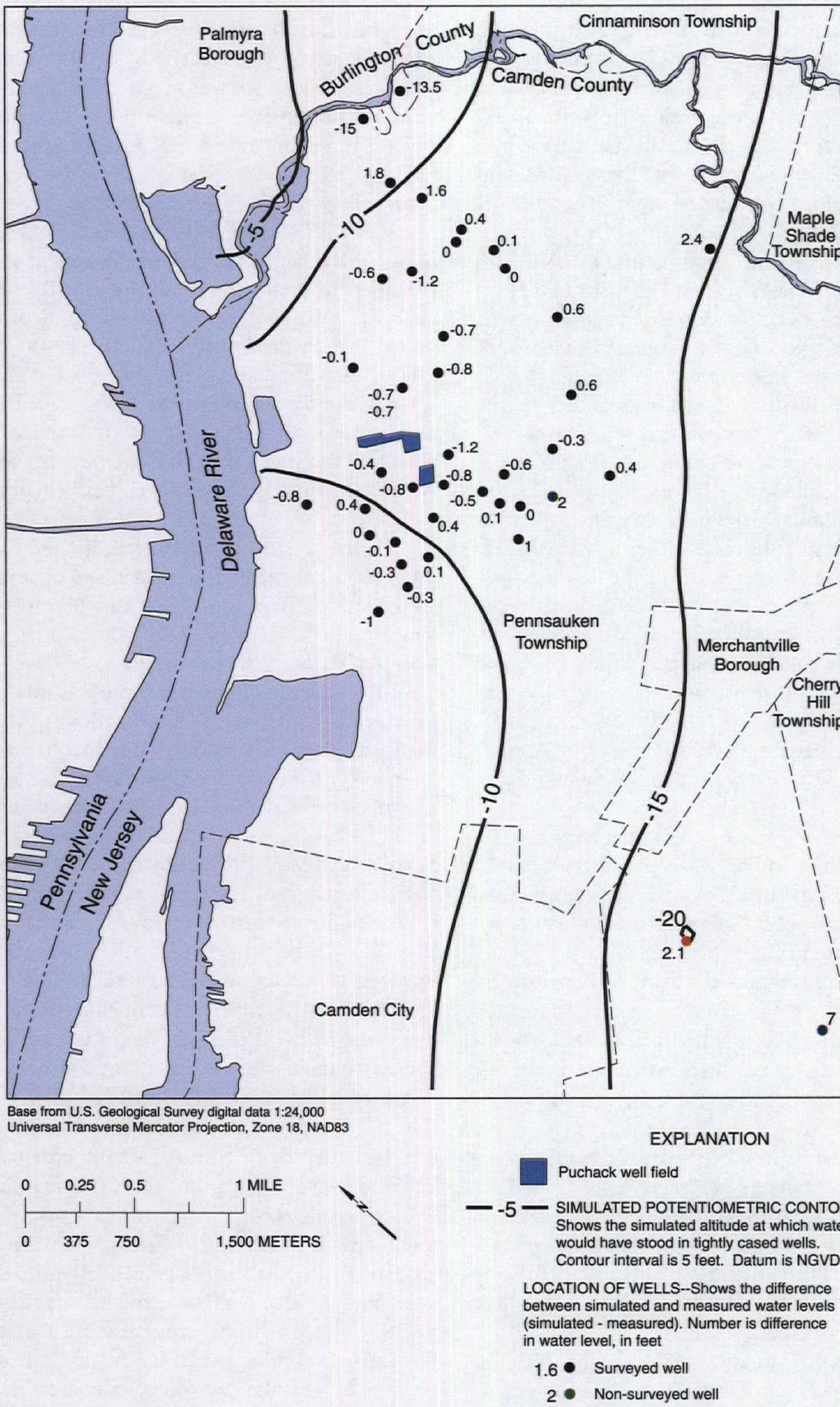

Figure 16. Simulated potentiometric surface and residuals of the Middle aquifer of the Potomac-Raritan-Magothy aquifer system, Pennsauken Township and vicinity, Camden County New Jersey, April 2001.

Simulated water levels in the Intermediate sand in April 2001 are shown in figure 17. Residuals in the Intermediate sand were within the calibration criterion at 29 of the 31 wells, and most residuals were within +/- 0.5 ft (fig. 17). One of the measurements that did not meet the calibration criterion is from a well located north of the Puchack well field near Pennsauken Creek; the simulated water level was 6.4 ft lower than the measured. The other measurement is from a well located downdip from the Puchack well field; the simulated water level was 2.7 ft higher than the measured level.

Simulated water levels in the Lower aquifer in April 2001 are shown in figure 18. Residuals at surveyed wells in the Lower aquifer were within the calibration criteria at 46 of the 50 surveyed wells (fig. 18). In general, the simulated water levels were low in an area from the western part of the Puchack well field northwest to the Delaware River and in areas to the northeast of the Puchack well field. The simulated water levels tended to be lower in areas downgradient from the Puchack well field. Residuals near or at pumped wells were higher than at surveyed wells, but were within +/- 10 ft except for one well in the Morris well field along Pennsauken Creek. Residuals at three of the seven non-surveyed wells were outside the calibration critieria, but these wells were located away from the area of interest at the Puchack well field. Simulated water levels were low at two non-surveyed wells located along the Delaware River and Pennsauken Creek. Simulated water levels were high at a well located downdip from the Puchack well field near the model boundary. The RMSE values for the Lower aquifer in April 2001 were lower for the surveyed wells than for the non-surveyed wells.

Water-level differences at nested wells were compared for the April 2001 calibration period because the additional wells drilled during 1998-2001 provided the most complete data set of measurements at nested wells. The well nests for which vertical gradient data were available are listed in table 6. The measured and simulated water levels at wells completed in different model layers are shown along with the simulated and measured water-level differences across the confining units at that point. The residual is the simulated water-level difference minus the measured water-level difference. The confining-unit model layer to which the water-level differences and the residual apply is shown in the last column (table 6). At nests where wells were not completed in the Intermediate sand, water-level differences were calculated for the entire C2 confining unit only (rather than for the C2-A and C2-B subunits). C2-A is the less permeable of the confining units that compose C2; therefore, for well nests where only C2 data were available, the C2 data were analyzed along with the C2-A data.

For the nested wells that straddle confining unit C-2A (or both C-2A and C-2B), the comparison between the simulated and measured differences across the confining units indicates that the model results are within +/- 1.0 ft at 19 of the 27 nests (fig. 19; table 6). In most cases, the vertical flow is downward from the Middle aquifer into the Intermediate sand. The MAE of the differences is 1.02 ft, and the RMSE is 1.9 ft at the 27 well nests for which water-level difference data were available. All but three of the residuals of the water-level differences were within +/- 1.5 ft. The difference at one well nest (PSLF MW-11) north of the Puchack well field is 8.68 ft. This well nest is away from the main area of interest and near the Pennsauken Creek where the geology of the Middle aquifer is more complex; therefore, less weight was given to the measurement. The well nests with differences larger than the calibration criteria are distributed throughout the model area. In general, there was a range of differences over small distances, and it was difficult to reduce the differences without creating larger differences at nearby wells. At three wells nests (PSLF MW-6, MW-12, and MW-19), the simulated vertical gradient at the well nest was in the opposite direction from the measured vertical gradient. At the PSLF and the MW-19 nests only, both of which are located north of the Puchack well field, the measured vertical gradient was upward from the Intermediate sand to the Middle aquifer, whereas the simulated flow direction was downward (as occurred in most of the well nests). At the MW-12 nest, the measured flow was downward, whereas the simulated flow was upward (MW-12 is the only well nest where this occurs in C2 or C2-A).

At the nested wells that straddle confining unit C-2B, the differences between the simulated and measured differences across the confining units were all within +/- 1 ft (fig. 20 and table 6). The MAE of the differences is 0.19 ft and the RMSE is 0.35 ft at the 21 well nests where water-level difference data were available. In most cases, flow was downward from the Intermediate sand into the Lower aquifer. At 8 of the 21 well nests, however, the simulated flow direction was in the opposite direction of the measured flow direction. The simulated flow direction was downward into the Lower aquifer at all but 3 of the 21 nests completed in C2-B. The three well nests (MW-12, MW-29, and MW-30) are downgradient from the chromium-contaminated area. The remaining five well nests, where the simulated flow was in the opposite direction from the measured flow (MW-2, MW-5, MW-22, MW-27, and MW-34), are at the locations where the simulated vertical flow was upward (from the Lower aquifer into the Intermediate sand). In all but one of these well nests (MW-2), the water-level differences across confining unit C2-B were small (measured water-level differences were less than 0.1 ft.) These areas of measured upward flow are distributed throughout the plume area on a scale finer than that used for the zones of aquifer horizontal hydraulic conductivity and confining unit vertical hydraulic conductivity.

In general, simulated water levels for April 2001 tend to be low (as much as 8.2 ft below measured water levels) in updip areas near the Delaware River and Pennsauken Creek and tend to be high (as much as 3 ft below measured water levels at surveyed wells) in downdip areas near the southeastern model boundary. In confining units C2-A and C2-B, simulated upward vertical flow resulted at well nests in areas downgradient from the chromium plume area. Simulated water levels also tend to be high in this area. In general, the match between simulated and measured water levels and simulated and measured water-level differences and between simulated and measured flow directions at nested wells in the vicinity of the chromium contamination is acceptable.

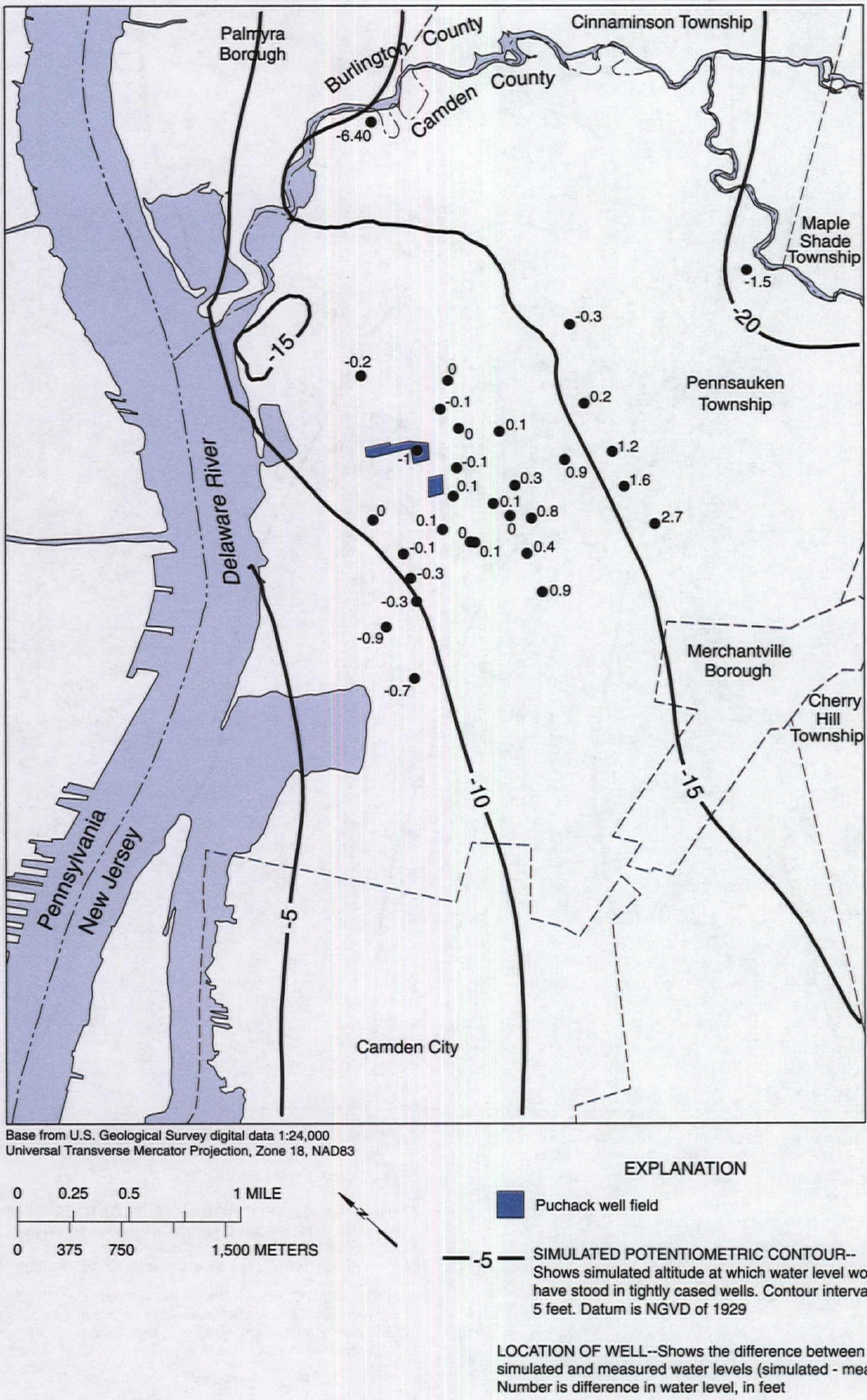

Figure 17. Simulated potentiometric surface and residuals of the Intermediate sand, Pennsauken Township and vicinity, Camden County, New Jersey, April 2001.

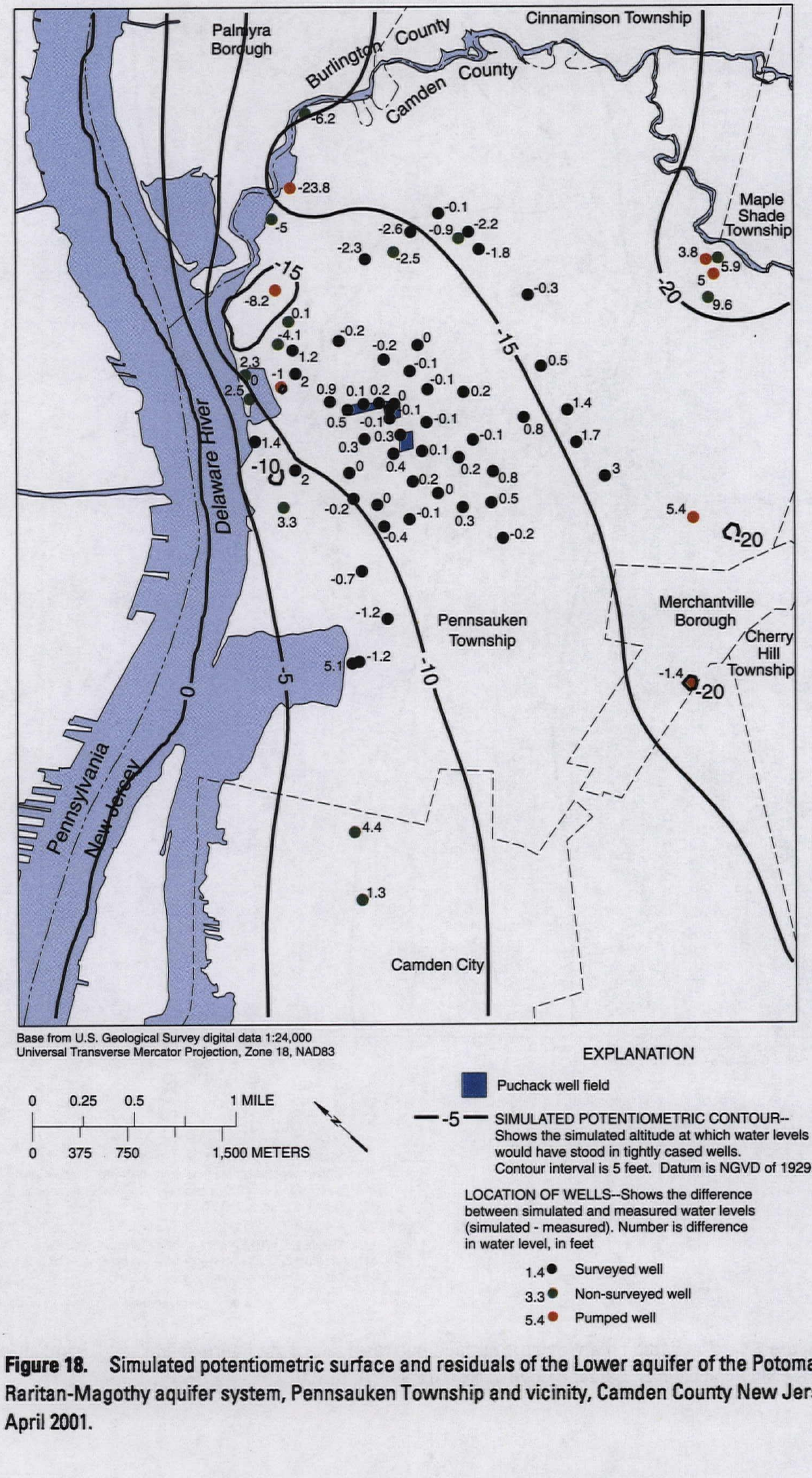

Figure 18. Simulated potentiometric surface and residuals of the Lower aquifer of the Potomac-Raritan-Magothy aquifer system, Pennsauken Township and vicinity, Camden County New Jersey, April 2001.

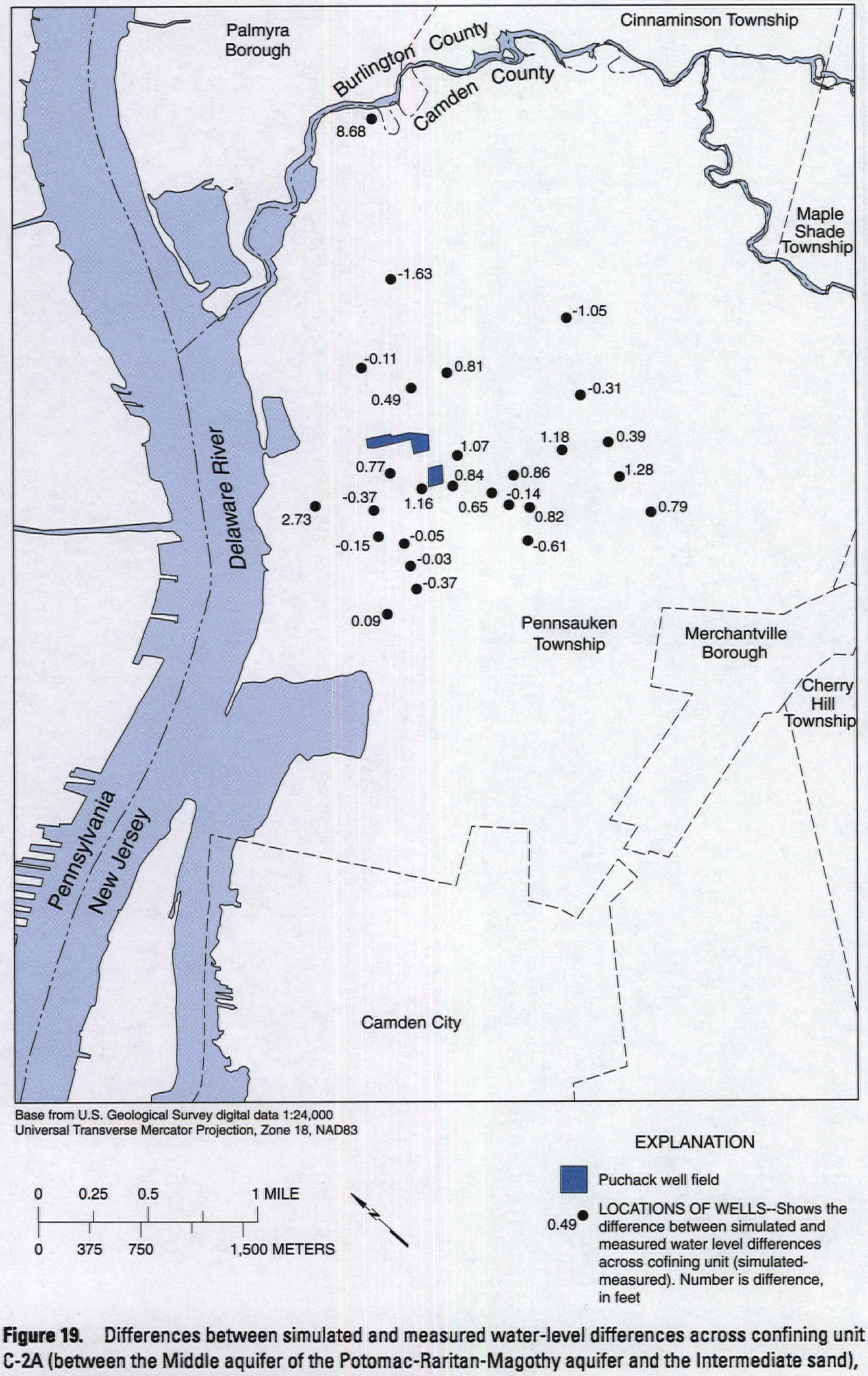

Figure 19. Differences between simulated and measured water-level differences across confining unit C-2A (between the Middle aquifer of the Potomac-Raritan-Magothy aquifer and the Intermediate sand), Pennsauken Township and vicinity, Camden County, New Jersey.

Table 6. Simulated and measured water-level differences in nested wells in Pennsauken Township and vicinity Camden County, New Jersey

[Well locations shown in figure 10; NGVD29, National Geodetic Vertical Datum of 1929]

Well nest identifier[1]	U.S. Geological Survey well number	Model layer	Measured altitude of water level (in feet above or below NGVD of 1929)	Measured water-level difference[2] (feet)	Simulated altitude of water level (in feet above or below NGVD of 1929)	Simulated water-level difference (feet)	Residual[3] (feet)	Confining unit
CCMW-2	7- 854	5	-11.26	-2.37	-11.81	-1.51	0.86	C-2A
	7- 853	7	-13.63		-13.33			
CCMW-4	7- 856	5	-9.84	-2.12	-10.59	-.96	1.16	[4]C-2
	7- 855	10	-11.96		-11.56			
PSLF MW-11	7- 964	3	7.95	-16.87	-7.09	-8.19	8.68	C-2A
	7- 965	7	-8.92		-15.28			
PSLF MW-6	7- 960	5	-12.19	.33	-12.83	-1.3	-1.63	[4]C-2
	7- 961	9	-11.86		-14.13			
MW-1	7- 907	5	-7.4	-.77	-8.39	-.68	.09	C-2A
	7- 908	7	-8.17	-.25	-9.06	-.1	.15	C-2B
	7- 906	11	-8.42		-9.16			
MW-2	7- 909	7	-8.67	.51	-9.33	-.04	-.55	C-2B
	7- 910	10	-8.16		-9.36			
MW-3	7- 911	5	-12.67	-.51	-11.64	-1.12	-.61	C-2A
	7-1045	7	-13.18	-.15	-12.76	-.1	.05	C-2B
	7- 912	11	-13.33		-12.86			
MW-4	7- 913	5	-11.82	-2.28	-11.82	-1.46	.82	[4]C-2
	7- 914	9	-14.1		-13.29			
MW-5	7- 916	5	-10.22	-2	-10.99	-1.16	.84	C-2A
	7- 917	7	-12.22	.01	-12.15	-.01	-.02	C-2B
	7- 918	10	-12.21		-12.16			
MW-6	7- 919	3	-10.27	-2.29	-11.43	-1.22	1.07	A-2C1, C-2A
	7-1016	7	-12.56	-.03	-12.65	-.02	.01	C-2B
	7- 920	10	-12.59		-12.67			
MW-7	7- 922	5	-10.14	-1.57	-10.56	-.8	.77	[4]C-2
	7- 921	11	-11.71		-11.36			
MW-8	7- 923	5	-8.74	-3.06	-9.5	-.33	2.73	[4]C-2
	7- 924	11	-11.8		-9.83			
MW-9	7- 925	3	-11.79	-.05	-12.53	-.04	.01	A-2C1
	7- 926	5	-11.84	-.99	-12.57	0.5	.49	C-2
	7- 927	11	-12.83		-13.07			
MW-10	7- 928	5	-9.55	-.34	-9.56	-.49	-.15	[4]C-2
	7- 929	11	-9.89		-10.05			
MW-11	7-1015	7	-13.79	-.05	-13.65	-.03	.02	C-2B
	7-1014	11	-13.84		-13.67			
MW-12	7-1044	3	-13.84	-.04	-13.50	-.02	.02	A-2C1
	7-1007	5	-13.88	-3.19	-13.51	-1.91	1.28	C-2A
	7- 930	7	-17.07	-.04	-15.42	.03	.07	C-2B
	7-1006	11	-17.11		-15.39			
MW-13	7-1013	3	-14.03	-1.63	-13.46	-1.94	-.31	A-2C1, C-2A
	7-1012	7	-15.66	-.26	-15.43	0	.26	C-2B
	7-1011	10	-15.92		-15.43			
MW-15	7-1060	7	-11.57	-.02	-11.39	-.07	-.05	C-2B
	7-1059	9	-11.59		-11.47			

Table 6. Simulated and measured water-level differences in nested wells in Pennsauken Township and vicinity Camden County, New Jersey—Continued

[Well locations shown in figure 10; NGVD29, National Geodetic Vertical Datum of 1929]

Well nest identifier[1]	U.S. Geological Survey well number	Model layer	Measured altitude of water level (in feet above or below NGVD of 1929)	Measured water-level difference[2] (feet)	Simulated altitude of water level (in feet above or below NGVD of 1929)	Simulated water-level difference (feet)	Residual[3] (feet)	Confining unit
MW-16	7-1035	5	-10.21	-0.19	-9.85	-0.56	-0.37	C-2A
	7-1034	7	-10.4	-.03	-10.42	-.01	.02	C-2B
	7-1033	10	-10.43		-10.43			
MW-17	7-1026	7	-11.37	-1	-12.37	-.07	.93	C-2B
	7-1025	10	-12.37		-12.44			
MW-19	7-1022	5	-12.47	.01	-12.61	-.1	-.11	C-2A
	7-1028	7	-12.46	-.53	-12.71	-.52	.01	C-2B
	7-1027	11	-12.99		-13.23			
MW-20	7-1068	7	-12.88	-.18	-13.02	-.17	.01	C-2B
	7-1067	11	-13.06		-13.19			
MW-21	7-1038	3	-12.21	-1.01	-13.03	-.20	.81	C-2A
	7-1037	7	-13.22	-.33	-13.23	-.33	0	C-2B
	7-1036	11	-13.55		-13.57			
MW-22	7-1024	7	-13.12	.05	-13.13	-.07	-.12	C-2B
	7-1023	11	-13.07		-13.2			
MW-23	7-1063	7	-10.2	-.02	-10.27	-.07	-.05	C-2B
	7-1062	9	-10.22	-.09	-10.34	0	.09	C-2B
	7-1061	11	-10.31		-10.34			
MW-24	7-1032	3	-11.63	-1.23	-11.49	-1.37	-.14	A-2C1, C-2A
	7-1031	7	-12.86		-12.86			
MW-25	7-1021	5	-10.89	-2	-11.39	-1.35	.65	C-2A
	7-1020	7	-12.89	-.04	-12.74	-.02	.02	C-2B
	7-1019	11	-12.93		-12.76			
MW-26	7-1054	5	-9.21	-.43	-9.12	-.8	-.37	C-2A
	7-1053	7	-9.64		-9.92			
MW-27	7-1057	5	-9.17	-.7	-9.4	-.73	-.03	C-2A
	7-1056	7	-9.87	.04	-10.13	-.09	-.13	C-2B
	7-1055	11	-9.83		-10.23			
MW-29	7-1040	5	-15.96	-2.39	-14.05	-1.6	.79	C-2A
	7-1030	7	-18.35	-.29	-15.66	.02	.31	C-2B
	7-1029	11	-18.64		-15.64			
MW-30	7-1046	5	-14.28	-2.48	-13.43	-2.09	.39	C-2A
	7-1008	7	-16.76	-.13	-15.52	.03	.16	C-2B
	7-1009	11	-16.89		-15.49			
MW-31	7-1066	3	-14.4	-1.19	-13.64	-2.24	-1.05	A-2C1, C-2A
	7-1065	7	-15.59	-.12	-15.88	-.1	.02	C-2B
	7-1064	10	-15.71		-15.98			
MW-34	7-1050	3	-12.38	-3.03	-12.64	-1.85	1.18	A-2C1, C-2A
	7-1049	7	-15.41	.08	-14.48	-.01	-.09	C-2B
	7-1048	11	-15.33		-14.5			

[1]The name of the grouping or nest of wells used for identification purposes.

[2]The water-level difference is the water level in the well below the confining unit minus the water level above the confining unit. Negative differences indicate a downward gradient.

[3]The residual is the simulated difference minus the measured difference.

[4]C-2 denotes a confining unit composed of both C-2A and C-2B. Wells are not available to determine vertical gradients of the Intermediate sand at these locations.

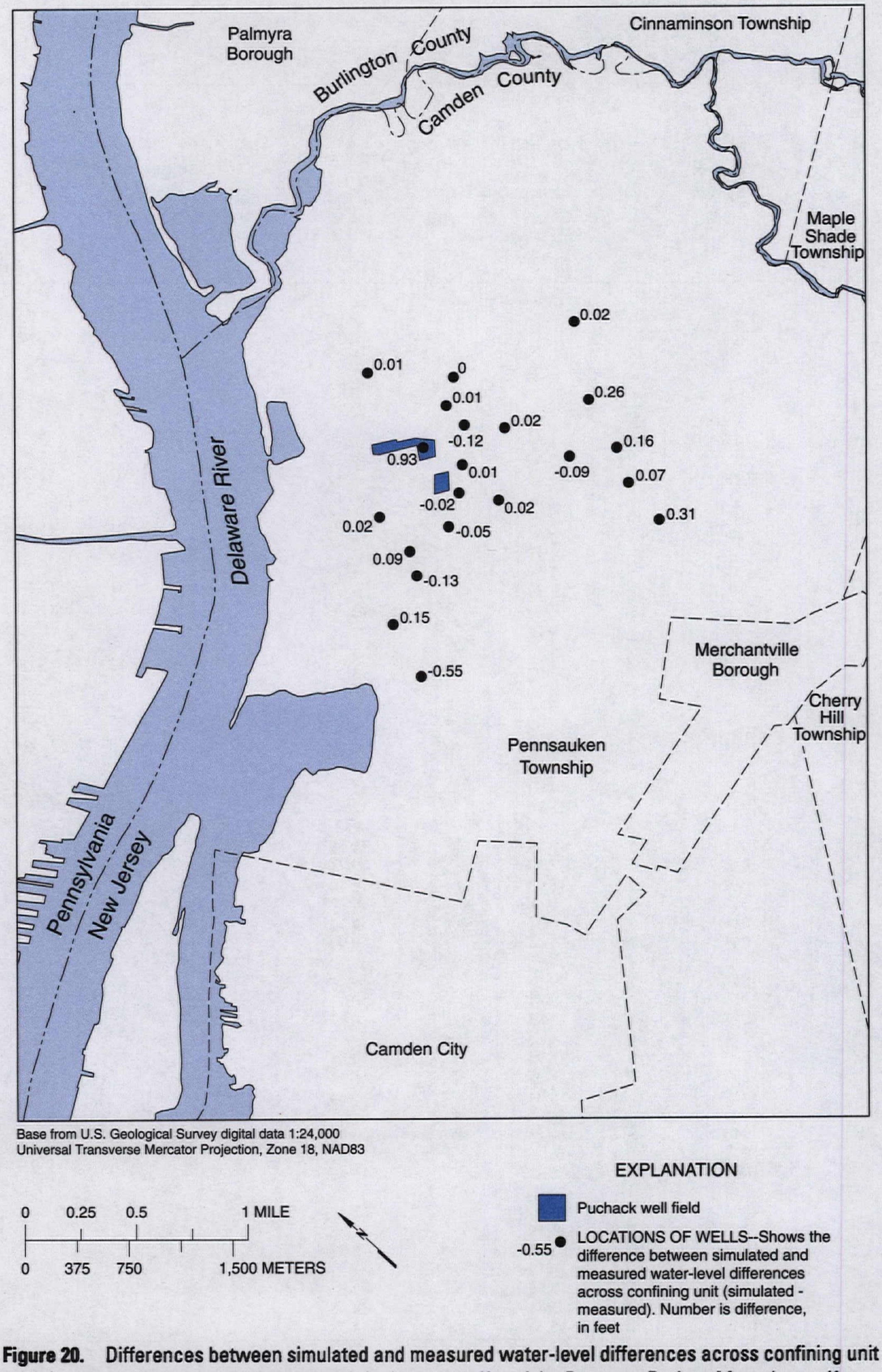

Figure 20. Differences between simulated and measured water-level differences across confining unit C-2B (between the Intermediate sand and the Lower aquifer of the Potomac-Raritan-Magothy aquifer system), Pennsauken Township and vicinity, Camden County, New Jersey.

Simulation of Delaware Gardens Aquifer Test

In August 1995, a long-term (30 day) aquifer test was conducted at one of the Merchantville-Pennsauken Water Company wells in the Delaware Gardens well field (Delaware Gardens well No. 1; fig. 21) to evaluate the hydraulic connection between the Lower aquifer and the Delaware River near the well field. The test was conducted from August 3 to September 1, 1995 (Ground Water Associates, 1995b). The pumping rate was not directly measured during the test but was estimated from a relation between pressure at the well and discharge that was determined during a previous aquifer test at the same location (Ground Water Associates, 1995a). The estimated discharge for the 30-day test was 900 gal/min.

The main goal of the simulation of the Delaware Gardens aquifer test was to test the model response to the changing flow conditions during the test, so the main emphasis of the analysis was on matching drawdowns rather than matching water levels.

During calibration, the drawdown part of the aquifer test was simulated to test the model connection between the ground-water-flow system and the Delaware River. The locations of the pumped well and observation wells used in the test are shown in figure 21. During simulation, all the wells were shifted so that well 1 was at the center of the model grid cell in which it was located (where the well was simulated in the finite-difference approach). In this way, the water-level data from the observation well reflects the true distance from the simulated well. This also allowed the data from the nearby observation wells to be analyzed even though the wells were located in the same model grid cell. Withdrawal data from August 1995 used in the simulation are listed in table 3.

Simulated and measured responses to the pumping were compared at the pumped well (Well 1), five observation wells in the Lower aquifer (L1, R1, R2, P1, and P2), and two wells in the overlying Middle aquifer (S1 and S2). Water levels measured in the pumped well were adjusted to account for the well loss in order to estimate the water level in the aquifer just outside the well bore. The well loss was estimated using distance-drawdown data from the aquifer test for periods of 5, 10, and 23 days. Distance-drawdown graphs were prepared and lines were fit to the data for each period (Driscoll, 1986). Drawdowns in the aquifer just outside the well were estimated using these lines. The well efficiency was calculated as the estimated drawdown in the aquifer just outside the well divided by the measured drawdown in the well. The average well efficiency was 71 percent. This value was used to adjust the measured water levels in well 1 for comparison with the simulated water levels in the aquifer.

Initial simulation of the Delaware Gardens aquifer test was performed early in the overall calibration process to evaluate the estimates of riverbed hydraulic conductivity used in the model. Once reasonable values were obtained in the simulation of the aquifer test, these data were used in the steady-state simulations of March 1998, April 1998, and April 2001. At the end of the calibration to these data sets, all model-input data were updated in the transient model of the Delaware Gardens aquifer test. Recharge and specific-storage values were tested during the simulation of the Delaware Gardens aquifer test. The same recharge rates were used in the final simulation of the Delaware Gardens aquifer test as were used in the calibration of the model to the March 1998, April 1998, and April 2001 steady-state simulations. Storage parameters were adjusted until the shape of hydrographs representing simulated water levels early in the aquifer test matched that of the measured water levels. Specific-storage values of $1x10^{-5}$ were used for the confined parts of all model layers. Specific-yield values of 0.25 were used for the unconfined parts of all model layers.

Graphs of the simulated and measured water levels during the test at six wells are shown in figure 22. The simulation of the aquifer test generally reproduced the shape of the measured water-level hydrograph and the general magnitude of drawdown at wells P1, P2, R2, and L1. The graphs of measured water levels for these wells show that water levels in the Lower aquifer leveled off about 5 days into the test. Water levels began to decline later in the test, probably because of ambient changes in water levels in the area. Assuming that the magnitude of the recovery should be similar to the magnitude of the drawdown, changes in water levels observed during the recovery part of the test were used as a guide to determine the time during which the effects of the pumped well on drawdown would be small. The magnitude of the recoveries corresponded to drawdowns that occurred during the aquifer test at about day 5 (or in some cases from 5 to 10 days). Water levels began to drop 5 to 10 days after the start of the test (fig. 22).

The simulated and measured water levels and drawdowns 1, 5, 10, and 23 of the test are presented in table 7. The simulated drawdowns at the observation wells after 5 days (shown in bold in table 7) are within +/- 1.5 ft of the measured drawdown at all of the observation wells. The difference in drawdown shown for the last day of the aquifer test (day 23) was affected by the ambient decline in water level. The simulated drawdown at day 5 at all of the observation wells was greater than the measured drawdown. This difference is probably because the transmissivity used in the model (18,000–20,000 ft^2/d) was too low. The transmissivity estimated for the 72-hour aquifer test (Ground Water Associates, 1995a) was 27,000 ft^2/d. Graphs of water-level data were not available for wells S1 and R1, but the water levels in these wells were measured manually on day 23. The simulated drawdown at these wells on day 23 was within +/- 1 .5 ft of the measured drawdown.

The graphs of the simulated and observed water levels at wells S2 and the pumped well (Well 1) don't match as closely as those for the other observation wells. Well S2 is screened in the Middle aquifer, whereas the pumped well and the observation wells shown in figure 22 are screened in the Lower aquifer. The simulated response in well S2 occurred earlier than the measured response (the measured decline also might result because of ambient declines in water level). Storage values in the model were adjusted until simulated water levels matched the measured water levels. In order to match the shape of the curves of the water levels to those of the wells completed in the Lower aquifer, a storage value of $1x10^{-5}$ was used for all model

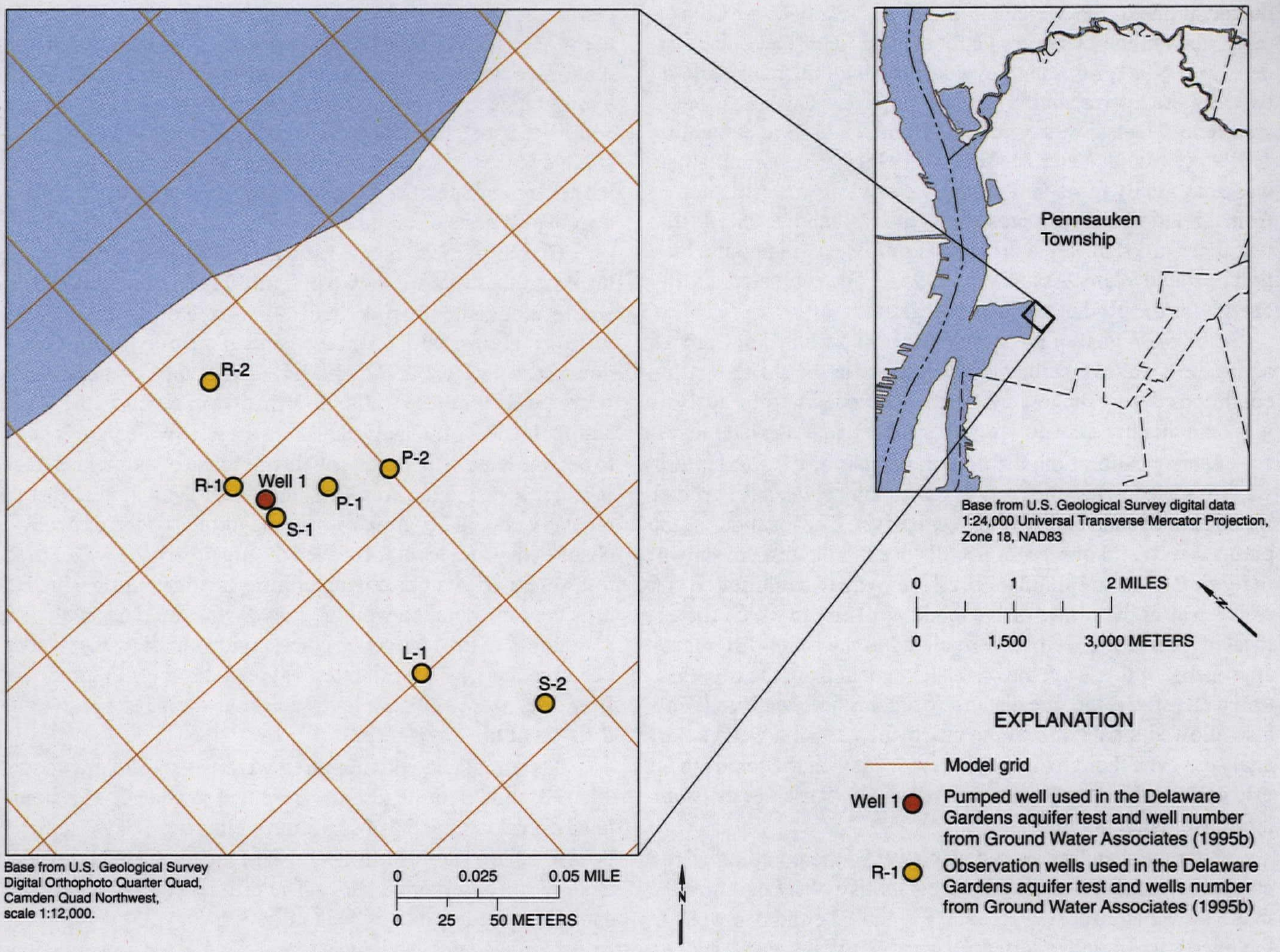

Figure 21. Location of wells used in the Delaware Gardens aquifer test, Pennsauken Township, Camden County, New Jersey.

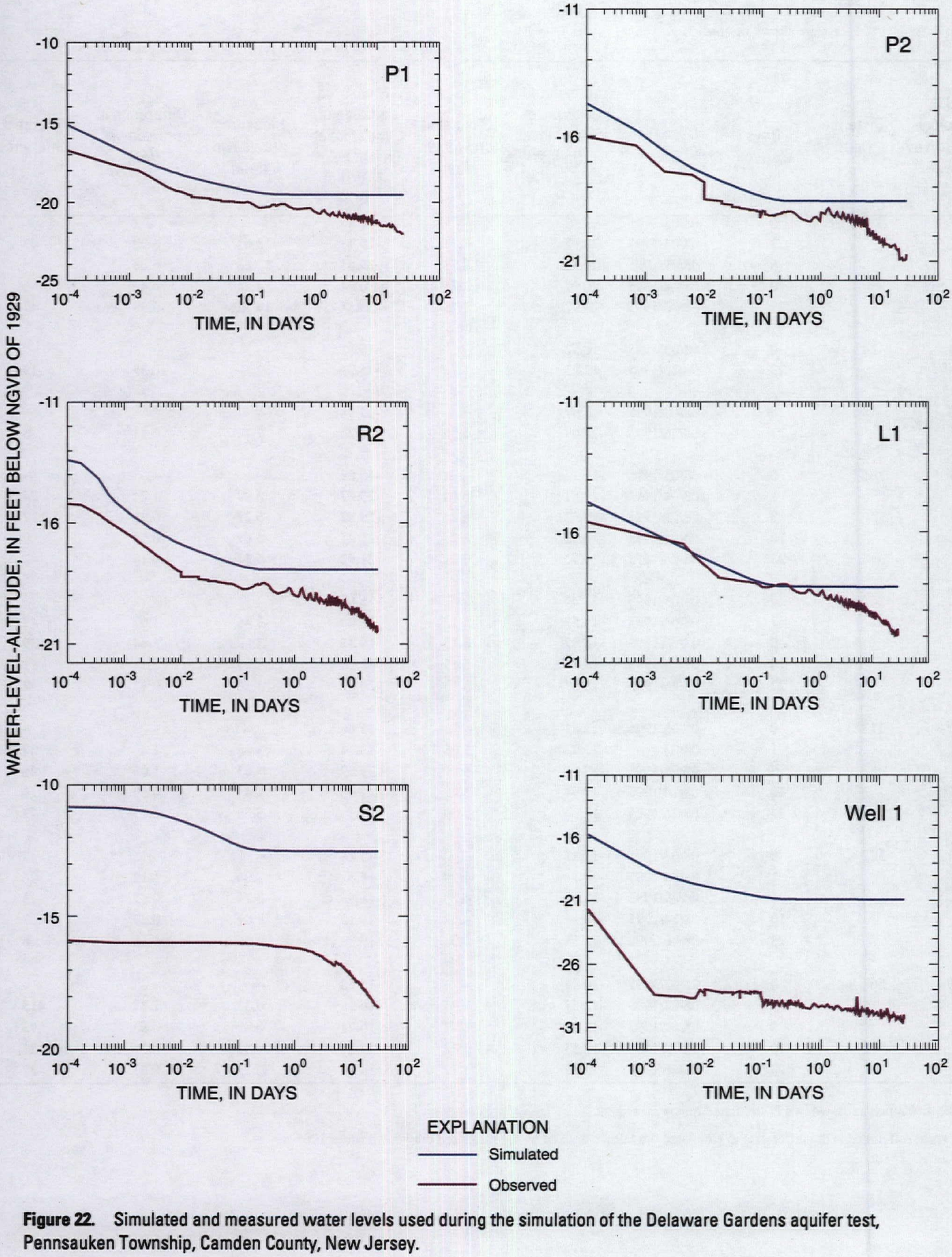

Figure 22. Simulated and measured water levels used during the simulation of the Delaware Gardens aquifer test, Pennsauken Township, Camden County, New Jersey.

Table 7. Simulated and measured drawdowns at observation wells and pumped well during the Delaware Gardens aquifer test, Pennsauken Township, Camden County, New Jersey

[--, no data; data at 5 days are shown in **bold**]

U.S. Geological Survey well number	Distance (feet)	Days elapsed	Date	Simulated altitude of water level (in feet below NGVD of 1929)	Simulated drawdown (feet)	Measured altitude of water level (in feet below NGVD of 1929)	Measured drawdown (feet)	Difference in drawdown[1] (feet)	Percent difference[2]
Well 1	0	0	08/03/1995	-13.17	--	-15.8	--	--	--
		1	08/04/1995	-20.91	7.74	-29.43	13.63	-6.08	-43
		5	**08/09/1995**	**-20.92**	**7.75**	**-29.63**	**13.83**	**-6.08**	**-44**
		10	08/14/1995	-20.92	7.75	-30.04	14.24	-6.49	-46
		23	08/26/1995	-20.92	7.75	-30.53	14.73	-6.98	-47
S1	34	0	08/03/1995	-10.52	--	-13.81	--	--	--
		23	08/26/1995	-12.23	1.71	-15.91	2.1	-0.39	-19
R1	58	0	08/03/1995	-13.07	--	-15.38	--	--	--
		23	08/26/1995	-20.03	6.96	-22.78	7.4	-0.44	-6
P1	105	0	08/03/1995	-13.32	--	-15.58	--	--	--
		1	08/04/1995	-19.51	6.19	-20.57	4.99	1.2	24
		5	**08/09/1995**	**-19.52**	**6.2**	**-20.87**	**5.29**	**0.91**	**17**
		10	08/14/1995	-19.52	6.2	-21.25	5.67	0.53	9
		23	08/26/1995	-19.52	6.2	-21.92	6.34	-0.14	-2
P2	209	0	08/03/1995	-13.44	--	-15.63	--	--	--
		1	08/04/1995	-18.57	5.13	-19.09	3.46	1.67	48
		5	**08/09/1995**	**-18.57**	**5.13**	**-19.32**	**3.69**	**1.44**	**39**
		10	08/14/1995	-18.57	5.13	-20.26	4.63	0.5	11
		23	08/26/1995	-18.57	5.13	-20.89	5.26	-0.13	-2
R2	213	0	08/03/1995	-12.85	--	-15.06	--	--	--
		1	08/04/1995	-17.93	5.08	-18.74	3.68	1.4	38
		5	**08/09/1995**	**-17.94**	**5.09**	**-19.09**	**4.03**	**1.06**	**26**
		10	08/14/1995	-17.94	5.09	-19.46	4.4	0.69	16
		23	08/26/1995	-17.94	5.09	-20.3	5.25	-0.15	-3
L1	382	0	08/03/1995	-13.81	--	-15.14	--	--	--
		1	08/04/1995	-18.1	4.29	-18.3	3.06	1.13	36
		5	**08/09/1995**	**-18.11**	**4.3**	**-18.93**	**3.79**	**0.51**	**13**
		10	08/14/1995	-18.11	4.3	-19.15	4.01	0.29	7
		23	08/26/1995	-18.11	4.3	-19.8	4.66	-0.36	-8
S1	567	0	08/03/1995	-10.81	--	-15.82	--	--	--
		1	08/04/1995	-12.51	1.7	-16.15	0.33	1.37	415
		5	**08/09/1995**	**-12.53**	**1.72**	**-16.71**	**0.89**	**0.83**	**93**
		10	08/14/1995	-12.53	1.72	-17.24	1.42	0.3	21
		23	08/26/1995	-12.53	1.72	-18.17	2.35	-0.63	-27

[5]The difference in drawdown is simulated minus measured.

[6]Percent difference is the difference in simulated drawdown divided by the measured drawdown times 100.

ayers. The general shape of the simulated response at well 1 matched measured water levels, but the simulated drawdown was too small. This difference may indicate that the estimated well efficiency of 71 percent for the well was too large.

Summary of Calibration

A variety of simulations of different flow conditions were used to obtain a robust model calibration. The overall model calibration using the results of the March 1998, April 1998, and April 2001 steady-state simulations and the transient simulation of the Delaware Gardens aquifer test is summarized in this section.

The model was accepted as calibrated on the basis of an overall evaluation of the calibration data sets. The model simulation using the March 1998 and April 2001 data sets was different. The simulated water levels for March 1998 generally were high in the Middle and Lower aquifers, and the residuals exceeded the calibration criteria at many wells. The simulated water levels for April 2001, however, were much closer to the measured water levels and actually were slightly lower in the Middle aquifer and the Intermediate sand when the mean error was taken into account (table 5). Because the April 2001 data set was more complete (it included additional wells) and because more nested wells were available for calibration, more emphasis was placed on calibration to the April 2001 data set than on the calibration to March or April 1998 data. Differences in model response during March 1998 and April 2001 could be the result of changes in pumping distribution at the Morris well field that could not be included in the model because data on pumping rates at individual wells were not available. Differences also could be the result of changes in recharge rate between the two time periods that were not accounted for in the model.

The simulation of the Delaware Gardens aquifer test demonstrates that the model effectively incorporates interaction with the Delaware River and that the model also simulates the aquifer response to changing flow conditions well. Estimates of the storage coefficient determined during the simulation of the Delaware Gardens aquifer test can be used to simulate historical ground-water withdrawal patterns around the Puchack well field.

Simulation of Baseline Conditions

The ground-water-flow model described in this report can be used to simulate alternatives that will be considered as part of the feasibility study at the Puchack Superfund site. A baseline simulation was developed as a common starting point for the simulation of feasibility study alternatives. The water-use data set developed for the baseline simulation is based on the average annual 1998-2000 ground-water withdrawals; however, the baseline alternative also will include the effects of changes in possible future withdrawals.

Ground-water withdrawal data for use in the baseline alternative were developed by updating the withdrawal values from 1998 through 2000 and gathering information about the future needs and upgrades to the water systems in the study area. Baseline withdrawal data are shown in figure 1 and table 3. Two potential changes in withdrawals need to be considered: (1) The Merchantville-Pennsauken Water Company has proposed an additional well pumping 1 Mgal/d at the Delaware Gardens location (fig. 1). (2) The city of Camden plans to increase the withdrawals at the Morris and Delair well field from 12 Mgal/d to 20 Mgal/d. Preliminary alternatives were simulated to evaluate the effects of the proposed changes in withdrawals from these well fields on the advective transport near the Puchack well-field site. Withdrawals from the proposed Delaware Garden well were included in the baseline withdrawal data set to provide a conservative estimate in case the well field becomes active; the withdrawals did not appreciably affect the advective movement of chromium under either natural conditions or remedial alternatives. The increased withdrawals projected by the city of Camden for the Morris and Delair well field were not included in the baseline withdrawal data set because the additional 8 Mgal/d would have a substantial effect on the movement of chromium under natural conditions and remedial alternatives. The effects of the projected increased withdrawals at the Morris and Delair well field can be simulated explicitly as part of the remedial alternatives.

The simulated water levels in the Middle aquifer, Intermediate sand, and Lower aquifer under baseline conditions are shown in figures 23 to 25, respectively. Flow in the Middle aquifer is from recharge and from induced flow from the Delaware River and Pennsauken Creek in the outcrop area. Additional flow is from the area of inflow along the model boundaries to the northeast and southwest towards areas of high leakage to the Intermediate sand and Lower aquifer and to the southeastern model boundary. The low water levels in the Middle aquifer just to the northeast of the Puchack well field are the result of a strong vertical connection in this area between the Middle aquifer and the underlying Intermediate sand (fig. 8) and the withdrawals from the Lower aquifer. Flow rates across the bottom of the Middle aquifer and the Intermediate sand (figs. 23 and 24) show areas of strong vertical connection between the aquifers.

Water levels in the Intermediate sand and Lower aquifer are dominated by leakage from the Delaware River and downdip flow to well fields in areas in Camden County outside the model area. The water levels in the Intermediate sand and Lower aquifer were similar and generally show ground-water movement from recharge areas near and under the Delaware River to the east-southeast towards pumping centers located downdip from the model area. The effects of withdrawals just inside the southeastern model boundary were seen as cones of depression or upgradient bends in the contour lines. These effects were the result of withdrawals at the Merchantville-Pennsauken Water Company's Park Avenue, Marion, and Woodbine well fields from the Lower aquifer. Withdrawals

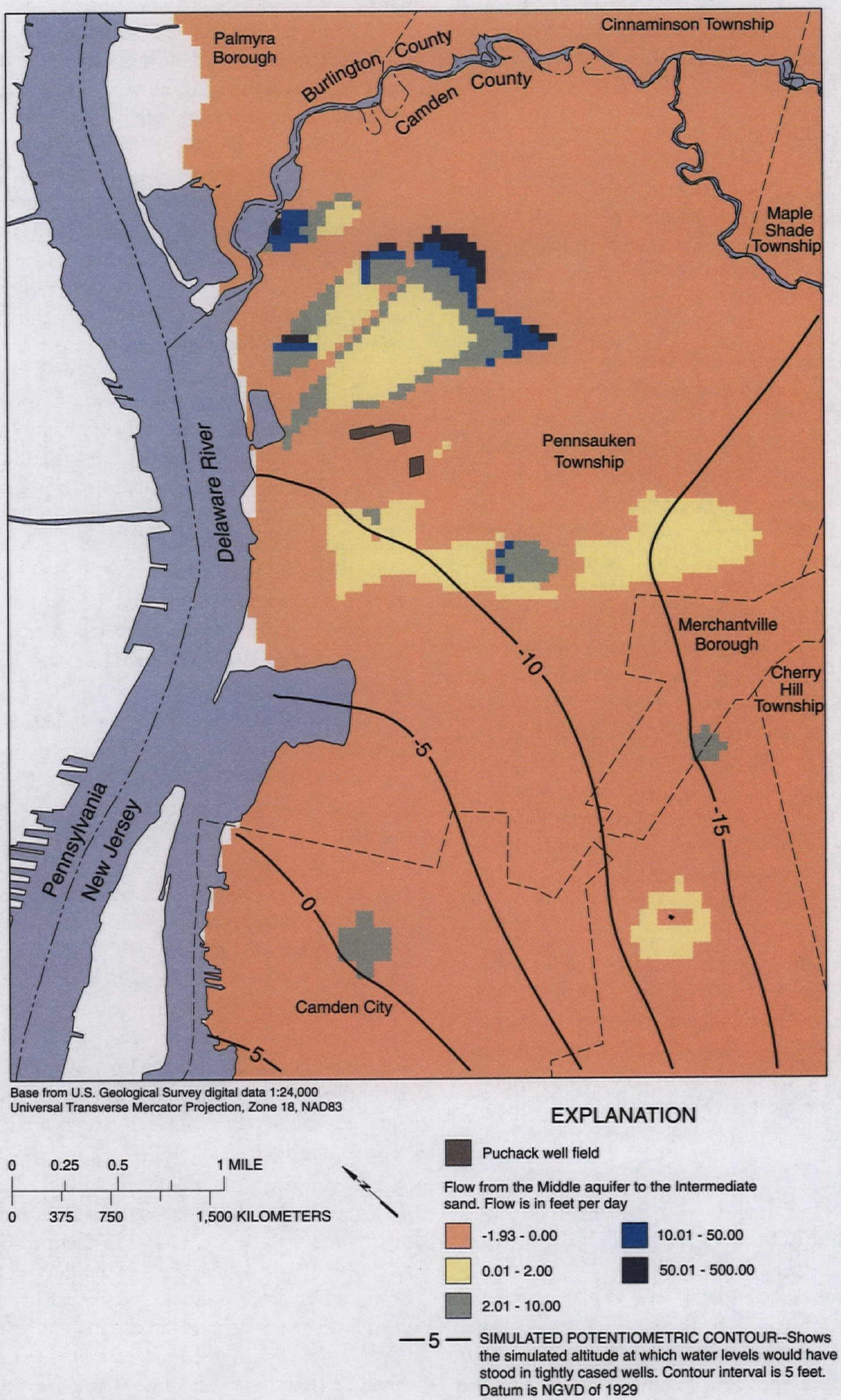

Figure 23. Simulated potentiometric surface of the Middle aquifer of the Potomac-Raritan-Magothy aquifer system under baseline conditions, Pennsauken Township and vicinity, Camden County, New Jersey.

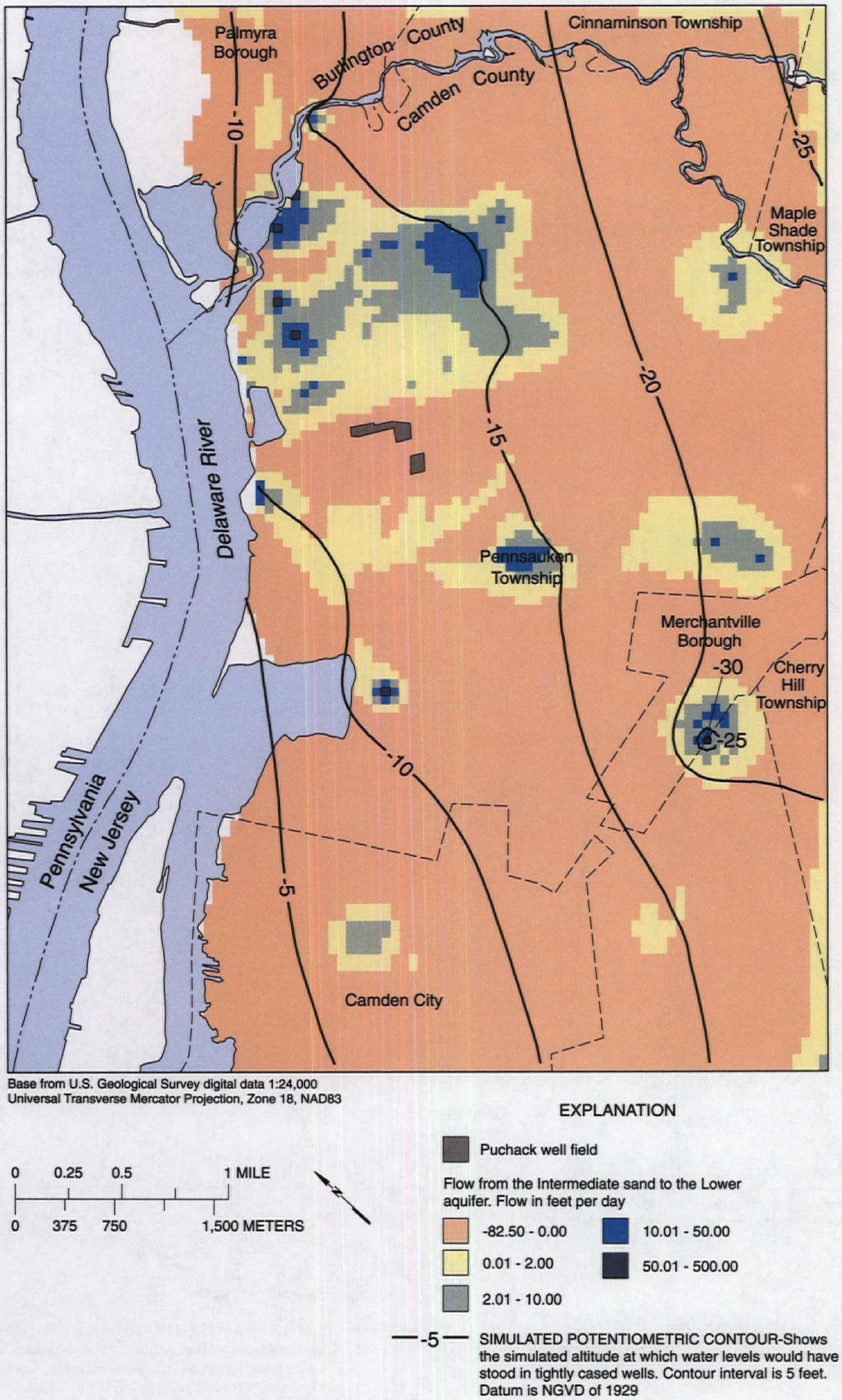

Figure 24. Simulated potentiometric surface of the Intermediate sand under baseline conditions, Pennsauken Township and vicinity, Camden County, New Jersey.

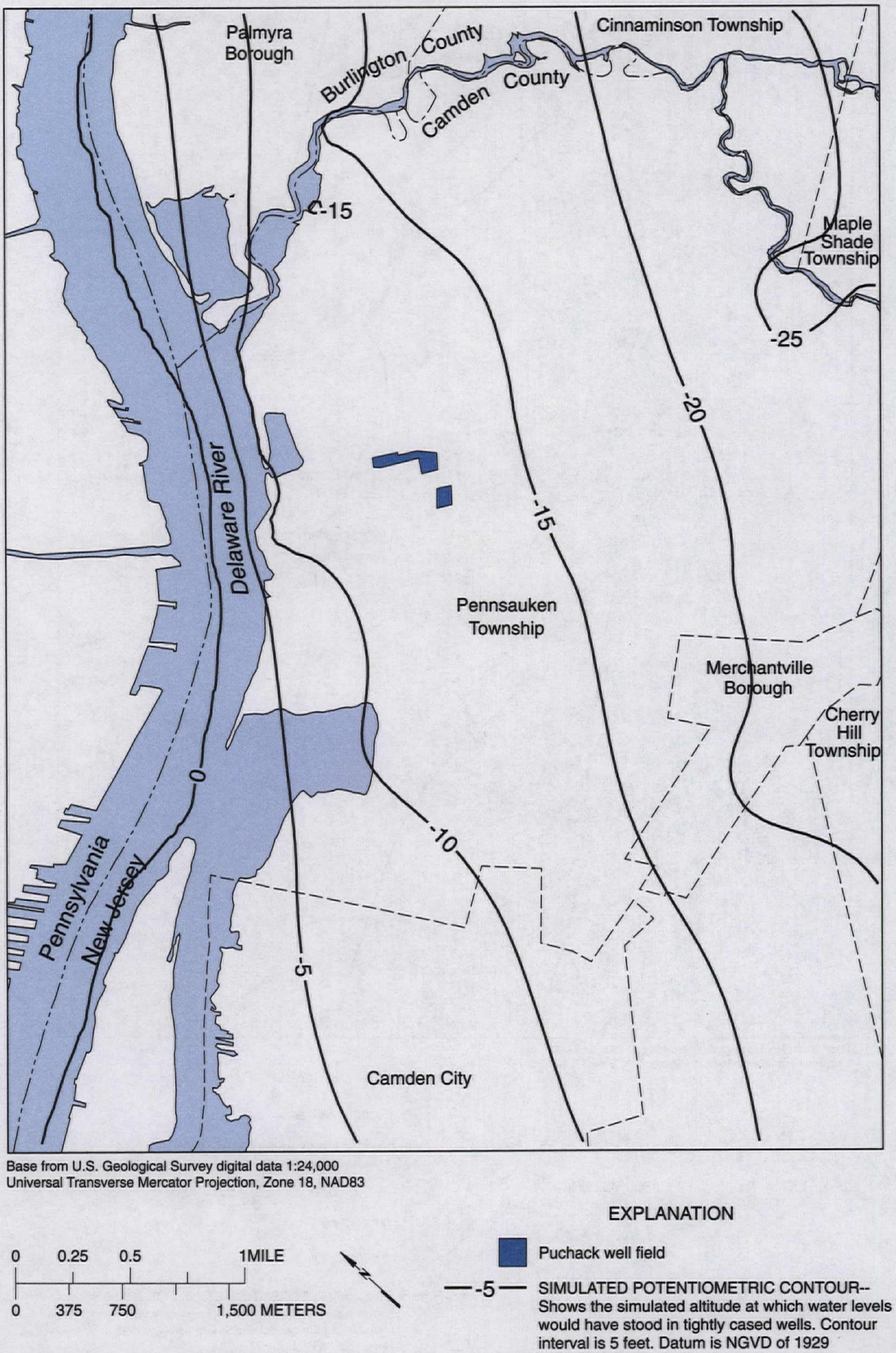

Figure 25. Simulated potentiometric surface of the Lower aquifer of the Potomac-Raritan-Magothy aquifer system under baseline conditions, Pennsauken Township and vicinity, Camden County, New Jersey.

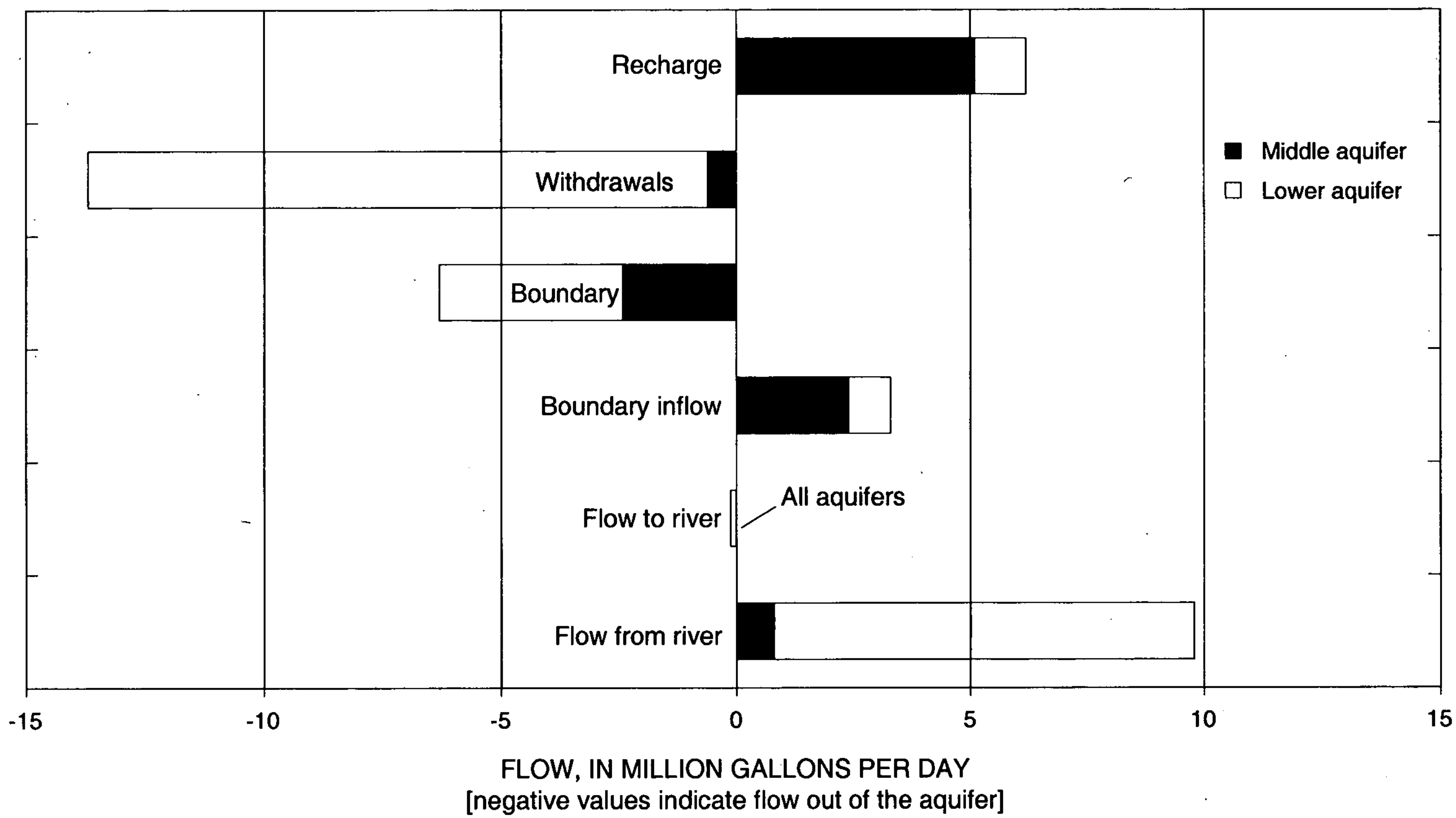

Figure 26. Ground-water flow budget for the Potomac-Raritan-Magothy aquifer system under baseline conditions, Pennsauken Township and vicinity, Camden County, New Jersey.

from wells in areas nearest the river (Morris and Delair and Delaware Gardens well fields) did not produce cones of depression (that are visible with the 5-ft contour intervals) as in downdip areas because of the considerable volume of water supplied by the Delaware River to wells in the Lower aquifer. Withdrawals at the Delaware Gardens well field would affect local water levels to some degree but not to the extent of withdrawals in downdip areas.

The simulated flow budget for the Potomac-Raritan-Magothy aquifer system under baseline conditions for the Pennsauken Township area is shown in figure 26. For each budget term, the total flow rate is shown and the part of each flow term from the three aquifers also is shown. Outflow from the aquifer system is dominated by withdrawals from the Lower aquifer within the model area , but flow downdip towards pumping centers outside the model area accounts for a large outflow from the ground-water-flow system (this outflow is divided between the Middle and Lower aquifers). The largest source of water to the aquifer system is flow from the Delaware River directly into the Lower aquifer where the aquifer subcrops in the riverbed. Recharge to the Middle aquifer is an appreciable term and includes recharge that occurs in areas where the Upper aquifer has been dewatered as a result of the withdrawals from the Lower aquifer.

Summary and Conclusions

In Pennsauken Township, Camden County, local drinking-water supplies from the Potomac-Raritan-Magothy aquifer system have been contaminated by hexavalent chromium at concentrations that exceed the New Jersey maximum contaminant level of 100 micrograms per liter. In particular, ground water underlying the Puchack well field has been affected adversely to the point where, since 1998, water is no longer withdrawn from this well field for public supply. The area that encompasses the Puchack well field was added to the National Priorities List in 1998.

A ground-water-flow model was developed to investigate advective transport of chromium-contaminated ground water in Pennsauken Township and vicinity. A revised hydrogeologic framework of the area was prepared to support the flow model. An 11-layer representation of the hydrogeologic units was used rather than the more general 5-layer breakdown used in previous regional studies in order to provide the detail needed to characterize the location of the chromium plume and the movement of ground water in the area. The revised framework includes the Intermediate sand layer, an important sand that is present in the confining unit between the Middle and Lower aquifers. Additional layers were added to subdivide the Middle and Lower aquifers to represent changes in properties within the aquifers.

A finite-difference model was developed to simulate ground-water flow and the advective transport of chromium-contaminated ground water in the aquifers of the Potomac-Raritan-Magothy aquifer system in the Pennsauken Township area. The model was imbedded within a larger regional model of the Potomac-Raritan-Magothy aquifer system that was used to provide boundary conditions for the local model. Hydrogeologic properties (aquifer transmissivity and confining unit vertical hydraulic conductivity) were updated for the local model area to reflect values used in the local model. Recharge was assigned on the basis of predominant land use and ranged from 6 to 14 inches per year. Streambed sediments underlying the Delaware River were characterized as high, moderate, or low permeability, and the horizontal hydraulic conductivity values used ranged from 0.00028 ft/d to 28 ft/d. Horizontal hydraulic conductivities used in the calibrated model ranged from 100 ft/d for the Upper aquifer to 400 ft/d for the most productive unit (lowermost) in the Lower aquifer. Zones of vertical hydraulic conductivity for confining units were delineated on the basis of geophysical and drillers' logs. Relative permeabilities for each confining unit were assigned as "very low", "low", "moderate", "moderately high", "high" or "very high". The vertical hydraulic conductivities of the confining units in each zone were adjusted during model calibration and ranged from 0.0002 to 0.5 ft/d.

The model was calibrated using steady-state data from March and April 1998 and April 2001. Simulation of the March and April 1998 conditions allowed for comparison of measured and simulated recoveries of wells near the Puchack well field when Puchack well 1 was temporarily shut down. Transient simulation of an aquifer test near the Delaware River was used to help characterize the horizontal hydraulic conductivity of the riverbed sediments. Results from the calibrated model indicate that the Delaware River contributes substantial flow to the ground-water system from areas where the Middle and Lower aquifers crop out beneath the river. Vertical movement across confining units between the aquifers is highly variable and is important in the movement of contaminated ground water through the flow system.

Simulation of baseline conditions was conducted to provide a common simulation on which to base simulations of various alternatives during the feasibility study. Ground-water withdrawals in the baseline simulation averaged about 14 Mgal/d within the model area. Ground water in the Lower aquifer flowed from recharge areas and from the Delaware River downgradient to withdrawal wells and out of the model area towards regional pumping centers farther to the east.

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Appendix A. Simulated and measured water levels and residuals in the Potomac-Raritan-Magothy aquifer system, Pennsauken Township and vicinity, Camden County, New Jersey, March 1998 and April 2001

Appendix A: Simulated and measured water levels and residuals in the Potomac-Raritan-Magothy aquifer system, Pennsauken Township and vicinity, Camden County, New Jersey, March 1998 and April 2001

[NJDEP, New Jersey Department of Environmental Protection; --, data not available]

U.S. Geological Survey well number	Well name	NJDEP permit number	Aquifer code[1]	March 1998			April 2001		
				Measured altitude of water level (in feet above or below NGVD of 1929)	Simulated altitude of water level (in feet above or below NGVD of 1929)	Residual (simulated minus measured) (feet)	Measured altitude of water level (in feet above or below NGVD of 1929)	Simulated altitude of water level (in feet above or below NGVD of 1929)	Residual (simulated minus measured) (feet)
				Middle Aquifer					
5-1418	PSLF MW-12	31-26580	MRPAM	5.14	-8.39	-13.5	5.32	-8.21	-13.5
7-319	1R/BROWNING 1A	31-05641	MRPAM	-21.94	-16.06	5.9	-17.27	-17.01	2.1
7-568	LANDFILL 1	--	MRPAM	-9.5	-9.92	-.4	-11.39	-9.63	1.8
7-571	LANDFILL 4	--	MRPAM	-14.63	-12.18	2.5	--	--	--
7-575	BELL IND-1	31-01357	MRPAM	-17.44	-12.7	4.7	-14.37	-12.36	2
7-848	BISHOP EUSTACE PREP 1	31-17884	MRPAM	-28.53	-18.3	10.2	-26.05	-19.09	7
7-852	CAMDEN CITY MW-1B	31-37329	MRPAM	-12.88	-10.4	2.5	-9.87	-9.78	.1
7-854	CAMDEN CITY MW-2B	31-37327	MRPAM	-14.51	-12.32	2.2	-11.26	-11.81	-.6
7-856	CAMDEN CITY MW-4B	31-37360	MRPAM	-12.89	-11.34	1.5	-9.84	-10.59	-.8
7-907	PUCHACK MW-1S	31-51229	MRPAM	-9.34	-8.92	.4	-7.4	-8.39	-1
7-911	PUCHACK MW-3M	31-51222	MRPAM	-14.65	-12.08	2.6	-12.67	-11.64	1
7-913	PUCHACK MW-4M	31-51224	MRPAM	-14.42	-12.26	2.2	-11.82	-11.82	0
7-916	PUCHACK MW-5M	31-51695	MRPAM	-13.23	-11.67	1.6	-10.22	-10.99	-.8
7-919	PUCHACK MW-6M	31-51697	MRPAM	-13.2	-12.12	1.1	-10.27	-11.43	-1.2
7-922	PUCHACK MW-7M	31-51700	MRPAM	-13.43	-11.36	2.1	-10.14	-10.56	-.4
7-923	PUCHACK MW-8M	31-51702	MRPAM	-11.26	-10.28	1	-8.74	-9.5	-.8
7-925	PUCHACK MW-9S	31-51705	MRPAM	-15.66	-13.41	2.3	-11.79	-12.53	-.7
7-926	PUCHACK MW-9M	31-51704	MRPAM	-15.64	-13.46	2.2	-11.84	-12.57	-.7
7-928	PUCHACK MW-10M	31-51900	MRPAM	-12.13	-10.37	1.8	-9.55	-9.56	0
7-934	HOLMAN ENT P-45-D	31-45076	MRPAM	-20.2	-14.42	--	-17.32	-14.87	2.4
7-940	SUPER TIRE MW-2D	31-35902	MRPAM	-14.84	-12.62	2.2	--	--	--
7-943	KING ARTHUR MW-5S	31-36280	MRPAM	-11.62	-9.86	1.8	--	--	--
7-948	GSM MW-11	31-33572-1	MRPAM	-15.54	-14.24	1.3	-15.54	-13.55	--
7-950	SWOPE OIL GM-8S	31-32304-9	MRPAM	--	--	--	-13.59	-13.59	0
7-952	SWOPE OIL GM-7S	31-32304-1	MRPAM	--	--	--	-13.55	-13.44	.1

[1]Aquifer codes are MRPAM, Middle aquifer of the Potomac-Raritan-Magothy aquifer system , MRPAL, Lower aquifer of the Potomac-Raritan-Magothy aquifer system.

[2]Intermediate sand unit of the Lower aquifer of the Potomac-Raritan-Magothy aquifer system.

Appendix A: Simulated and measured water levels and residuals in the Potomac-Raritan-Magothy aquifer system, Pennsauken Township and vicinity, Camden County, New Jersey, March 1998 and April 2001—Continued

[NJDEP, New Jersey Department of Environmental Protection; --, data not available]

U.S. Geological Survey well number	Well name	NJDEP permit number	Aquifer code[1]	March 1998: Measured altitude of water level (in feet above or below NGVD of 1929)	March 1998: Simulated altitude of water level (in feet above or below NGVD of 1929)	March 1998: Residual (simulated minus measured) (feet)	April 2001: Measured altitude of water level (in feet above or below NGVD of 1929)	April 2001: Simulated altitude of water level (in feet above or below NGVD of 1929)	April 2001: Residual (simulated minus measured) (feet)
				Middle Aquifer—Continued					
7-954	PSLF MW-7	--	MRPAM	-16.46	-13.7	2.8	-13.32	-13.27	0
7-955	SWOPE OIL GM-2S	31-29668-8	MRPAM	--	--	--	-13.26	-12.89	.4
7-958	PSLF MW-5	31-18183	MRPAM	-14.88	-13.77	1.1	-12.04	-13.26	-1.2
7-960	PSLF MW-6	31-19602	MRPAM	-16.57	-13.33	3.2	-12.19	-12.83	-.6
7-962	PSLF MW-2 REPLACEMENT	31-17781	MRPAM	-20.22	-11.35	8.9	-12.66	-11.03	1.6
7-963	PSLF MW-13	31-29056-6	MRPAM	-2.8	-7.39	-4.6	--	--	--
7-964	PSLF MW-11	31-24601-1	MRPAM	-8.43	-7.3	1.1	7.95	-7.09	-15
7-1007	PUCHACK MW-12S	31-58577	MRPAM	--	--	--	-13.88	-13.51	.4
7-1013	PUCHACK MW-13M	31-58580	MRPAM	--	--	--	-14.03	-13.46	.6
7-1021	PUCHACK MW-25M	31-58575	MRPAM	--	--	--	-10.89	-11.39	-.5
7-1022	PUCHACK MW-19M	31-58628	MRPAM	--	--	--	-12.47	-12.61	-.1
7-1032	PUCHACK MW-24M	31-59205	MRPAM	--	--	--	-11.63	-11.49	.1
7-1035	PUCHACK MW-16M	31-58625	MRPAM	--	--	--	-10.21	-9.85	.4
7-1038	PUCHACK MW-21M	31-58685	MRPAM	--	--	--	-12.21	-13.03	-.8
7-1050	PUCHACK MW-34M	31-59811	MRPAM	--	--	--	-12.38	-12.64	-.3
7-1054	PUCHACK MW-26M	31-59895	MRPAM	--	--	--	-9.21	-9.12	.1
7-1057	PUCHACK MW-27M	31-59365	MRPAM	--	--	--	-9.17	-9.4	-.2
7-1066	PUCHACK MW-31M	31-59530	MRPAM	--	--	--	-14.4	-13.64	.8
7-1069	PUCHACK MW-21S	31-59925	MRPAM	--	--	--	-12.83	-13.55	-.7
				Lower Aquifer					
7-320	WOODBINE 1	31-04642	MRPAL	-28.4	-19.78	8.6	-20.78	-22.22	-1.4
7-335	MARION 1	31-02915	MRPAL	-28.78	-17.89	10.9	-23.66	-18.22	5.4
7-341	DELA GARDEN 2	31-01417	MRPAL	-9.55	-8.44	1.1	-13.12	-8.03	5.1
7-345	PARK AVE 5	31-00011	MRPAL	--	--	--	-28.05	-23.09	5
7-346	PARK AVE 3A	--	MRPAL	--	--	--	-28.76	-22.9	5.9
7-350	PARK AVE 2	51-00064	MRPAL	-29.95	-25.58	4.4	-28.78	-24.97	3.8
7-358	PUCHACK 4R/6-70	31-05450	MRPAL	-15.82	-13.38	2.4	-12.38	-12.04	.3
7-359	PUCHACK 5/5A	51-00059	MRPAL	-16.45	-13.84	2.6	-12.19	-12.25	-.1
7-363	PUCHACK 2	51-00057	MRPAL	-18.06	-14.53	3.5	-12.36	-12.25	.1
7-366	PUCHACK 1	51-00056	MRPAL	--	--	--	-12.34	-11.86	.5

Appendix A: Simulated and measured water levels and residuals in the Potomac-Raritan-Magothy aquifer system, Pennsauken Township and vicinity, Camden County, New Jersey, March 1998 and April 2001—Continued

[NJDEP, New Jersey Department of Environmental Protection; --, data not available]

U.S. Geological Survey well number	Well name	NJDEP permit number	Aquifer code[1]	March 1998			April 2001		
				Measured altitude of water level (in feet above or below NGVD of 1929)	Simulated altitude of water level (in feet above or below NGVD of 1929)	Residual (simulated minus measured) (feet)	Measured altitude of water level (in feet above or below NGVD of 1929)	Simulated altitude of water level (in feet above or below NGVD of 1929)	Residual (simulated minus measured) (feet)
				Lower Aquifer—Continued					
7-367	PUCHACK 3/3A	51-00058	MRPAL	-17.08	-14.17	2.9	-12.58	-12.39	.2
7-369	DELAIR 2	51-00054	MRPAL	-13.62	-9.31	4.3	--	--	--
7-370	DELAIR 3	51-00055	MRPAL	-11.24	-12.46	-1.2	--	--	--
7-372	NATIONAL HWY 1	31-05110	MRPAL	-18.05	-16.14	1.9	-14.65	-15.58	-.9
7-373	MORRIS 6	51-00051	MRPAL	--	--	--	-15.19	-13.18	2
7-374	MORRIS 9/9N	51-00076	MRPAL	-19.81	-13.75	6.1	-14.74	-13.57	1.2
7-375	MORRIS 8	31-00944	MRPAL	--	--	--	-14.58	-14.47	.1
7-377	MORRIS 7	51-00052	MRPAL	--	--	--	-9.95	-14.07	-4.1
7-379	MORRIS 10	31-04251	MRPAL	-16.89	-16.48	.4	-9.81	-17.98	-8.2
7-382	MORRIS 4A	31-04252	MRPAL	--	--	--	-8.79	-13.83	-5
7-386	MORRIS 3A	31-00945	MRPAL	--	--	--	4.65	-19.16	-23.8
7-387	MORRIS 2	--	MRPAL	-12.84	-16.22	-3.4	--	--	--
7-390	MORRIS 1	51-00050	MRPAL	--	--	--	-8.52	-14.74	-6.2
7-528	PUCHACK 6-75/7	31-08526	MRPAL	-17.18	-14.01	3.2	-12.54	-12.55	0
7-530	4R-A/PARK AVE 6	31-14564	MRPAL	-34.4	-22.65	11.8	-30.48	-20.93	9.6
7-535	TW-1-79	31-15367	MRPAL	--	--	--	-8.99	-7.62	1.4
7-536	TW-3-79/SEALED	31-15369	MRPAL	-21.96	-13.02	8.9	--	--	--
7-538	TW-5-79/SEALED	--	MRPAL	-24.03	-13.2	10.8	--	--	--
7-540	TW-7-79/SEALED	31-14569	MRPAL	-15.55	-13.07	2.5	--	--	--
7-545	MORRIS 11	31-15745	MRPAL	-18.14	-13.07	5.1	-14.11	-15.09	-1
7-547	54	31-18944	MRPAL	-12.01	-7.14	4.9	-11.57	-7.13	4.4
7-586	MORRIS 12	31-16814	MRPAL	--	--	--	-12.88	-10.61	2.3
7-587	MORRIS 13	31-16813	MRPAL	--	--	--	-11.57	-9.06	2.5
7-597	55	31-20270	MRPAL	-10.25	-7.25	3	-8.59	-7.29	1.3
7-602	NATIONAL HWY 2	31-19207	MRPAL	-14.48	-17.43	-3	--	--	--
7-855	CAMDEN CITY MW-4A	31-37359	MRPAL	-15.97	-12.86	3.1	-11.96	-11.56	.4
7-906	PUCHACK MW-1D	31-51230	MRPAL	-10.77	-9.93	.8	-8.42	-9.16	-.7
7-910	PUCHACK MW-2D	31-51227	MRPAL	-10.9	-9.91	1	-8.16	-9.36	-1.2
7-912	PUCHACK MW-3D	31-51223	MRPAL	-16.39	-13.47	2.9	-13.33	-12.86	.5
7-915	PUCHACK MW-4D	31-51225	MRPAL	-17.32	-13.95	3.4	-14.06	-13.29	.8

Appendix A: Simulated and measured water levels and residuals in the Potomac-Raritan-Magothy aquifer system, Pennsauken Township and vicinity, Camden County, New Jersey, March 1998 and April 2001—Continued

[NJDEP, New Jersey Department of Environmental Protection; --, data not available]

				March 1998			April 2001		
U.S. Geological Survey well number	Well name	NJDEP permit number	Aquifer code[1]	Measured altitude of water level (in feet above or below NGVD of 1929)	Simulated altitude of water level (in feet above or below NGVD of 1929)	Residual (simulated minus measured) (feet)	Measured altitude of water level (in feet above or below NGVD of 1929)	Simulated altitude of water level (in feet above or below NGVD of 1929)	Residual (simulated minus measured) (feet)
				Lower Aquifer—Continued					
7-918	PUCHACK MW-5D	31-51696	MRPAL	-15.82	-13.22	2.6	-12.21	-12.16	.1
7-920	PUCHACK MW-6D	31-51698	MRPAL	-16.34	-13.76	2.6	-12.59	-12.67	-.1
7-921	PUCHACK MW-7D	31-51699	MRPAL	-16.12	-13.26	2.9	-11.71	-11.36	.3
7-924	PUCHACK MW-8D	31-51701	MRPAL	-14.18	-11.57	2.6	-11.8	-9.83	2
7-927	PUCHACK MW-9D	31-51703	MRPAL	-17.56	-14.22	3.3	-12.83	-13.07	-.2
7-929	PUCHACK MW-10D	31-51901	MRPAL	-12.65	-11.25	1.4	-9.89	-10.05	-0.2
7-932	DELA GARDEN R-1	31-43420	MRPAL	-10.13	-8.69	1.4	-7.09	-8.27	-1.2
7-951	SWOPE OIL GM-8D	31-32306-5	MRPAL	--	--	--	-14.02	-15.84	-1.8
7-953	SWOPE OIL GM-7D	31-32305-7	MRPAL	--	--	--	-13.88	-16.07	-2.2
7-956	SWOPE OIL GM-2D	31-29669-6	MRPAL	--	--	--	-15.54	-15.64	-.1
7-957	PSLF MW-3D	31-26142-6	MRPAL	-16.29	-15.4	.9	-12.3	-14.85	-2.6
7-959	PSLF MW-5D	31-26143-4	MRPAL	-16.04	-14.97	1.1	-11.86	-14.41	-2.5
7-961	PSLF MW-6D	31-26141-8	MRPAL	-16.63	-14.65	2	-11.86	-14.13	-2.3
7-987	G-P GYPSUM CORP 1	--	MRPAL	--	--	--	-11.31	-7.96	3.3
7-1006	PUCHACK MW-12D	31-58576	MRPAL	--	--	--	-17.11	-15.39	1.7
7-1014	PUCHACK MW-11D	31-58583	MRPAL	--	--	--	-13.84	-13.67	.2
7-1018	CAMDEN CITY MW-1D	31-58629	MRPAL	--	--	--	-10.71	-10.84	-.1
7-1019	PUCHACK MW-25D	31-58573	MRPAL	--	--	--	-12.93	-12.76	.2
7-1023	PUCHACK MW-22D	31-58571	MRPAL	--	--	--	-13.07	-13.2	-.1
7-1025	PUCHACK MW-17D	31-58639	MRPAL	--	--	--	-12.37	-12.44	-.1
7-1027	PUCHACK MW-19D	31-58626	MRPAL	--	--	--	-12.99	-13.23	-.2
7-1029	PUCHACK MW-29D	31-59192	MRPAL	--	--	--	-18.64	-15.64	3
7-1033	PUCHACK MW-16D	31-58623	MRPAL	--	--	--	-10.43	-10.43	0
7-1036	PUCHACK MW-21D	31-58633	MRPAL	--	--	--	-13.55	-13.57	0
7-1039	PUCHACK MW-18D	31-59203	MRPAL	--	--	--	-12.9	-12.05	.9

Appendix A: Simulated and measured water levels and residuals in the Potomac-Raritan-Magothy aquifer system, Pennsauken Township and vicinity, Camden County, New Jersey, March 1998 and April 2001—Continued

[NJDEP, New Jersey Department of Environmental Protection; --, data not available]

U.S. Geological Survey well number	Well name	NJDEP permit number	Aquifer code[1]	March 1998			April 2001		
				Measured altitude of water level (in feet above or below NGVD of 1929)	Simulated altitude of water level (in feet above or below NGVD of 1929)	Residual (simulated minus measured) (feet)	Measured altitude of water level (in feet above or below NGVD of 1929)	Simulated altitude of water level (in feet above or below NGVD of 1929)	Residual (simulated minus measured) (feet)
				Lower Aquifer—Continued					
7-1042	PUCHACK MW-35D	31-59990	MRPAL	--	--	--	-12.42	-12.64	-.2
7-1047	PUCHACK MW-14 BETHEL-I	31-59764	MRPAL	--	--	--	-12.53	-12.25	.3
7-1048	PUCHACK MW-34D	31-59809	MRPAL	--	--	--	-15.33	-14.5	0.8
7-1051	PUCHACK MW-14D	31-59201	MRPAL	--	--	--	-11.84	-11.81	0
7-1055	PUCHACK MW-27D	31-59303	MRPAL	--	--	--	-9.83	-10.23	-.4
7-1058	PUCHACK MW-15D	31-59436	MRPAL	--	--	--	-11.7	-11.46	.2
7-1061	PUCHACK MW-23D	31-59366	MRPAL	--	--	--	-10.31	-10.34	0
7-1060	PUCHACK MW-15M	31-59438	MRPAL	--	--	--	-11.57	-11.39	.2
7-1063	PUCHACK MW-23M	31-59368	MRPAL	--	--	--	-10.2	-10.27	-.1
7-1064	PUCHACK MW-31D	31-59528	MRPAL	--	--	--	-15.71	-15.98	-.3
7-1067	PUCHACK MW-20D	31-59526	MRPAL	--	--	--	-13.06	-13.19	-.1
				Intermediate Sand					
7-342	DELA GARDEN 1A	31-05228	MRPAL[2]	-12.79	-9.18	3.6	--	--	--
7-851	CAMDEN CITY MW-1A	31-37328	MRPAL[2]	-14	-11.59	2.4	--	--	--
7-853	CAMDEN CITY MW-2A	31-37326	MRPAL[2]	-17.43	-14.09	3.3	-13.63	-13.33	.3
7-908	PUCHACK MW-1M	31-51228	MRPAL[2]	-10.47	-9.81	.7	-8.17	-9.06	-.9
7-909	PUCHACK MW-2M	31-51226	MRPAL[2]	-10.85	-9.87	1	-8.67	-9.33	-.7
7-914	PUCHACK MW-4I	31-52598	MRPAL[2]	-17.38	-13.95	3.4	-14.1	-13.29	.8
7-917	PUCHACK MW-5I	31-52597	MRPAL[2]	-15.82	-13.18	2.6	-12.22	-12.15	01
7-930	PUCHACK MW-12M	31-51906	MRPAL[2]	-20.45	-15.85	4.6	-17.07	-15.42	1.6
7-931	PUCHACK MW-14	31-52706	MRPAL[2]	-14.28	-11.96	2.3	-11.37	-11.26	.1
7-933	HOLMAN ENT P-47-D	31-45075	MRPAL[2]	-22.16	-21	1.2	-19.06	-20.52	-1.5
7-944	KING ARTHUR MW-5D	31-36279	MRPAL[2]	-12.76	-10.91	1.8	--	--	--
7-965	PSLF MW-11D	31-26140-0	MRPAL[2]	-11.82	-16.45	-4.6	-8.92	-15.28	-6.4
7-1008	PUCHACK MW-30I	31-58582	MRPAL[2]	--	--	--	-16.76	-15.52	1.2
7-1012	PUCHACK MW-13I	31-58579	MRPAL[2]	--	--	--	-15.66	-15.43	.2
7-1015	PUCHACK MW-11I	31-58584	MRPAL[2]	--	--	--	-13.79	-13.65	0.1

Appendix A: Simulated and measured water levels and residuals in the Potomac-Raritan-Magothy aquifer system, Pennsauken Township and vicinity, Camden County, New Jersey, March 1998 and April 2001—Continued

[NJDEP, New Jersey Department of Environmental Protection; --, data not available]

U.S. Geological Survey well number	Well name	NJDEP permit number	Aquifer code[1]	March 1998 Measured altitude of water level (in feet above or below NGVD of 1929)	March 1998 Simulated altitude of water level (in feet above or below NGVD of 1929)	March 1998 Residual (simulated minus measured) (feet)	April 2001 Measured altitude of water level (in feet above or below NGVD of 1929)	April 2001 Simulated altitude of water level (in feet above or below NGVD of 1929)	April 2001 Residual (simulated minus measured) (feet)
				Intermediate Sand—Continued					
7-1016	PUCHACK MW-6I	31-58637	MRPAL[2]	--	--	--	-12.56	-12.65	-.1
7-1020	PUCHACK MW-25I	31-58574	MRPAL[2]	--	--	--	-12.89	-12.74	.1
7-1024	PUCHACK MW-22I	31-58572	MRPAL[2]	--	--	--	-13.12	-13.13	0
7-1026	PUCHACK MW-17I	31-58640	MRPAL[2]	--	--	--	-11.37	-12.37	-1
7-1028	PUCHACK MW-19I	31-58627	MRPAL[2]	--	--	--	-12.46	-12.71	-.2
7-1030	PUCHACK MW-29I	31-59193	MRPAL[2]	--	--	--	-18.35	-15.66	2.7
7-1031	PUCHACK MW-24I	31-59204	MRPAL[2]	--	--	--	-12.86	-12.86	0
7-1034	PUCHACK MW-16I	31-58624	MRPAL[2]	--	--	--	-10.4	-10.42	0
7-1037	PUCHACK MW-21I	31-58634	MRPAL[2]	--	--	--	-13.22	-13.23	0
7-1043	PUCHACK MW-35I	31-59991	MRPAL[2]	--	--	--	-13.53	-12.64	.9
7-1045	PUCHACK MW-3I	31-59988	MRPAL[2]	--	--	--	-13.18	-12.76	.4
7-1049	PUCHACK MW-34I	31-59810	MRPAL[2]	--	--	--	-15.41	-14.48	.9
7-1052	PUCHACK MW-14I	31-59202	MRPAL[2]	--	--	--	-11.84	-11.81	0
7-1053	PUCHACK MW-26I	31-59894	MRPAL[2]	--	--	--	-9.64	-9.92	-.3
7-1056	PUCHACK MW-27I	31-59364	MRPAL[2]	--	--	--	-9.87	-10.13	-.3
7-1059	PUCHACK MW-15I	31-59437	MRPAL[2]	--	--	--	-11.59	-11.47	.1
7-1062	PUCHACK MW-23I	31-59367	MRPAL[2]	--	--	--	-10.22	-10.34	-.1
7-1065	PUCHACK MW-31I	31-59529	MRPAL[2]	--	--	--	-15.59	-15.88	-.3
7-1068	PUCHACK MW-20I	31-59527	MRPAL[2]	--	--	--	-12.88	-13.02	-.1

Appendix B. Simulated and measured water levels and drawdowns in the Potomac-Raritan-Magothy aquifer system, Pennsauken Township and vicinity, Camden County, New Jersey, March and April 1998

Appendix B: Simulated and measured water levels and drawdowns in the Potomac-Raritan-Magothy aquifer system, Pennsauken Township and vicinity, Camden County, New Jersey, March and April 1998

[NJDEP, New Jersey Department of Environmental Protection; NGVD of 1929, National Geodetic Vertical Datum of 1929]

U.S. Geological Survey well number	Well name	NJDEP permit number	Aquifer code [1]	Measured altitude of water level March 1998 (in feet above or below NGVD of 1929)	Measured altitude of water level April 1998 (in feet above or below NGVD of 1929)	Measured recovery (feet)	Simulated altitude of water level March 1998 (in feet above or below NGVD of 1929)	Simulated altitude of water level April 1998 (in feet above or below NGVD of 1929)	Simulated recovery (feet)	Residual (simulated recovery minus measured recovery) (feet)
7-358	PUCHACK 4R/6-70	31-05450	MRPAL	-15.82	-14.48	1.3	-13.38	-12.15	1.2	-0.1
7-359	PUCHACK 5/5A	51-00059	MRPAL	-16.45	-14.87	1.6	-13.84	-12.35	1.5	-.1
7-363	PUCHACK 2	51-00057	MRPAL	-18.06	-16.40	1.7	-14.53	-12.29	2.2	.6
7-367	PUCHACK 3/3A	51-00058	MRPAL	-17.08	-15.18	1.9	-14.17	-12.45	1.7	-.2
7-374	MORRIS 9/9N	51-00076	MRPAL	-19.81	-18.47	1.3	-13.75	-12.74	1.0	-.3
7-528	PUCHACK 6-75/7	31-08526	MRPAL	-17.18	-15.77	1.4	-14.01	-12.61	1.4	.0
7-540	TW-7-79/SEALED	31-14569	MRPAL	-15.55	-14.04	1.5	-13.07	-11.77	1.3	-.2
7-545	MORRIS 11	31-15745	MRPAL	-18.14	-17.03	1.1	-13.07	-11.96	1.1	.0
7-851	CAMDEN CITY MW-1A	31-37328	ISAND[2]	-14.00	-13.30	.7	-11.59	-10.81	.8	.1
7-853	CAMDEN CITY MW-2A	31-37326	ISAND[2]	-17.43	-16.64	.8	-14.09	-13.34	.8	.0
7-855	CAMDEN CITY MW-4A	31-37359	MRPAL	-15.97	-14.58	1.4	-12.86	-11.70	1.2	-.2
7-906	PUCHACK MW-1D	31-51230	MRPAL	-10.77	-10.30	.5	-9.93	-9.29	.6	.2
7-910	PUCHACK MW-2D	31-51227	MRPAL	-10.90	-10.57	.3	-9.91	-9.39	.5	.2
7-912	PUCHACK MW-3D	31-51223	MRPAL	-16.39	-15.70	.7	-13.47	-12.84	.6	-.1
7-915	PUCHACK MW-4D	31-51225	MRPAL	-17.32	-16.47	.8	-13.95	-13.28	.7	-.2
7-918	PUCHACK MW-5D	31-51696	MRPAL	-15.82	-14.68	1.1	-13.22	-12.24	1.0	-.2
7-920	PUCHACK MW-6D	31-51698	MRPAL	-16.34	-15.19	1.2	-13.76	-12.73	1.0	-.1
7-921	PUCHACK MW-7D	31-51699	MRPAL	-16.12	-14.24	1.9	-13.26	-11.58	1.7	-.2
7-924	PUCHACK MW-8D	31-51701	MRPAL	-14.18	-13.91	.3	-11.57	-10.52	1.1	.8
7-927	PUCHACK MW-9D	31-51703	MRPAL	-17.56	-15.99	1.6	-14.22	-13.00	1.2	-.4
7-929	PUCHACK MW-10D	31-51901	MRPAL	-12.65	-11.94	.7	-11.25	-10.28	1.0	.3

[1]Aquifer codes are MRPAM, Middle aquifer of the Potomac-Raritan-Magothy aquifer system, MRPAL, Lower aquifer of the Potomac-Raritan-Magothy aquifer system.

[2]Intermediate sand unit of the Lower aquifer of the Potomac-Raritan-Magothy aquifer system.

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